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FOREWORD: The various topics and sub-topics are listed alphabetically. It is suggested that related or functional topics should be reviewed when one desires all references on a given subject. The issue number (1 to 9) of the TRANSACTIONS precedes the page number.

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THE RETINAL SENSIBILITIES RELATED TO ILLUMINATING ENGINEERING.*

BY P. G. NUTTING.

Synopsis: The retinal sensibilities of importance in illuminating engineering are sensibility to brightness and brightness differences and sensibility to color and color differences. In this paper the various sensibilities and their inter-relations are outlined; data are summarized and methods of evaluating them described. Several direct applications of these data to illuminating problems are indicated.

Since the eye is the sole means of judging lighting, the various effects of light on the eye and its perceptive system are of vital importance in determining correct lighting. The more important relations between the visual sensation and the exciting light are listed below.

The relative brightness sensibility of the retina when viewing fields of any brightness. The intensity of the sensation depends directly upon this sensibility.

The sensibility to *differences* in brightness ranging from minimum contrast (photometric sensibility) to maximum contrast (glare limit) that may be comfortably viewed, all for fields of every brightness.

The *rate* at which adaptation occurs, from a high to a lower level and from a low to a higher. The extremes would be a complete drop from bright daylight to a dark room and going from complete darkness to bright sunlight.

The level of adaptation when *part* of the field of view is bright and part dark, with large and small fractions bright and with low and high differences.

* A paper presented at the ninth annual convention of the Illuminating Engineering Society, Washington, D. C., September 20-23, 1915.

Communication No. 29 from the Research Laboratory of the Eastman Kodak Company.

The normal *pupil area* for each mean brightness of field and the rate of opening and closing of pupil with given brightness differences. The flux density of light at the retina is directly proportional to the pupil area.

The relative sensibility of the retina to light of various wave-lengths (*visibility*) but otherwise the same. The visibility constant is the number of lumens in one watt.

The relative sensibility to differences in wave-length (*hue sensibility*) at various intensities. This integrates into the natural hue scale.

Sensibility to differences in *purity* ranging from nearly pure white to nearly pure spectrum hues in all parts of the spectrum.

THE BRIGHTNESS SENSATIONS.

The fundamental relation covering many of the brightness sensations is that between the intensity of the sensation and the brightness of the object viewed. The intensity of a sensation (if we may call it that) is not, of course, directly measured, but it may be determined by integrating the sensibility curves and these may be determined in several ways.

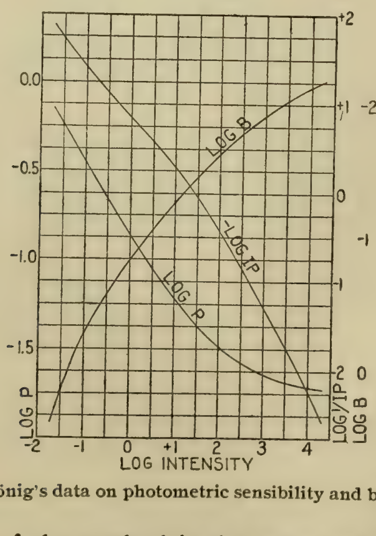

Fig. 1.—König's data on photometric sensibility and brightness.

The principle of the method is the same as in any instrument (an ammeter, say) in which a scale reading varies with a stimulus. The sensibility of the instrument, at any part of the scale,

is the derivative of the scale reading with respect to the stimulus and conversely the scale reading is the (general) integral of the sensibility with respect to the stimulus. In the case of the retina, the brightness sensation sought corresponds to the scale reading and the light flux density on the retina to the stimulus or independent variable.

Brightness Sensation Scale by Photometric Sensibility.—In this method the sensibility is derived from the least difference in brightness, (minimum contrast) that is just perceptible. According to Fechner's law this difference is a constant fraction of the brightness at which it is measured over a wide range of moderate intensities. In the table below and in Fig. 1 are given some data computed from data of König and Brodhun[1] for white light covering the range from the threshold of vision up to that of full sunlight on white paper.

In the first column are the intensities at which the differences were observed and in the following column the (fractional) differences observed. In the third column are the differences computed by the formula[2]

$$P = P_m + (1 - P_n)(I/I_0)^n,$$

in which $n = 0.45$, $I_0 = 0.0090$ (in König's units) and $P_m = 0.0175$. This is the constant (Fechner) fraction approached at moderate and higher brightness.

Brightness Sensation Data from König's Data.

I	P(obs.)	P(cal.)	IP	1/IP	B
20,000	0.0175	0.0189	350.0	0.0028	152.4
10,000	0.0176	0.0194	176.0	0.0057	135.0
5,000	0.0179	0.0202	89.5	0.0112	118.2
2,000	0.0181	0.0220	36.2	0.0276	96.8
1,000	0.0188	0.0230	18.8	0.0532	83.0
500	0.0192	0.0250	9.6	0.104	69.8
200	0.0222	0.0285	4.4	0.227	54.3
100	0.0298	0.0329	3.0	0.333	43.0
50	0.0324	0.0384	1.62	0.617	33.78
20	0.0396	0.0490	0.79	1.27	24.3
10	0.0477	0.0610	0.48	2.08	18.55
5	0.0593	0.0767	0.296	3.38	14.90
2	0.094	0.1066	0.190	5.26	9.28
1	0.123	0.1395	0.123	8.14	6.67
0.5	0.188	0.1845	0.094	10.6	4.75
0.2	0.283	0.2695	0.057	17.5	2.835
0.1	0.377	0.3625	0.038	26.3	1.848
0.05	0.484	0.4875	0.024	41.6	1.093
0.02	0.695	0.7285	0.013	77.0	0.421

[1] A König, *Ges. Abh.*, p. 115.

[2] Nutting, P. G., *B. S. Bull.*, V., p. 287, 1908.

The calculated curve rises slightly more rapidly at first. In the fourth column is the product IP or the least perceptible increment in König's brightness units. 1/IP in the next column is proportional to retinal sensibility. The values at the lower intensities are uncertain because the time of adaptation was not made uniform. In the final column B is the brightness sensation obtained by integrating dI/IP to obtain the formula[3]

$$B = K \log (1 + P_m)((I/I_0)^n - 1)^{1/n},$$

and calculating from this formula. These are the relative sensation intensities corresponding to the relative brightness of object viewed given in the first column.

König's brightness unit was that of a magnesium oxide surface illuminated by 10 sq. mm. of freezing platinum at 1 meter viewed through a pupil of 1 sq. mm. This is equivalent to 0.0036 millilambert. The corresponding flux density at the retina is 0.0144 lumen per square millimeter. When 1 millilambert is viewed by a normal eye through a pupil of 1 square millimeter, the light flux at the retina is 0.400 lumen per square millimeter.

Brightness Sensation, Threshold Method.—In the threshold method as used by the writer for determining retinal sensibility, the eye is accommodated to a large white field of uniform known brightness. In the center of this is a spot faintly illuminated from behind. Both spot and field illuminations are under accurate control over very wide ranges (*c. f.*, Fig. 3).

In operation, the test spot brightness is varied until the spot can just be seen as the field lighting is snapped off. This instantaneous threshold is taken as a measure of the sensibility of the retina at the field brightness used. Observations may be taken in a fraction of a second so that neither the change of adaptation of the retina nor the opening of the pupil are involved; data on these pupil openings are given later in this paper.

The instantaneous threshold, like the just noticeable difference, approaches a constant fraction (0.00022 for N) at the upper and the value unity at the lower limit of vision (0.000017 ml.). It is well represented by the formula

$$P = P_m + (1 - P_m)(B/B_0)^n,$$

in which $P_m = 0.00022$, $B_o = 0.000017$ ml., and $n = 0.49$.

[3] Nutting, P. G., *B. S. Bulletin*, V, p. 287, 1908.

Although this formula is of the same form as that for photometric sensibility above, the quantities involved are different. P and P_m are here the ratios of the instantaneous threshold brightness to the brightness of the field to which the eye is accommodated, P_m being the constant minimum value of this ratio approached at higher levels of accommodation. Brightnesses are in millilamberts.

The data obtained are listed in the following table. I is the field brightness, IP the minimum brightness perceptible on switching off the field light. The third column contains values of P computed from the formula. The fourth column headed IP is the instantaneous threshold observed, the fifth column its reciprocal—a quantity proportional to sensibility. Sensibility determined in this manner is a measure of the brightness required to just pick up objects when the eye is adapted to the brightnesses in the first column. B is the integral of the sensibility.

Brightness Sensation, Threshold Method.

I	P(cal.)	P(obs.)	IP	1/IP	B
0.0_417	1.00	1.00	0.0_417	58900.0	—
0.0_4257	0.813	0.81	0.0_4208	48100.0	0.204
0.0_4513	0.484	0.58	0.0_4298	33500.0	0.808
0.0_320	0.27	0.30	0.0_460	16666.0	2.02
0.002	0.047	0.096	0.0_3192	5210.0	8.47
0.02	0.015	0.031	0.0_362	1610.0	27.6
0.2	0.0045	0.0100	0.0020	500.0	86.8
1.21	0.0242	0.0244	0.0053	188.0	207.0
10.75	0.02205	0.02163	0.0175	58.0	562.0
54.0	0.0391	0.0387	0.0470	21.3	1180.0
262.0	0.03475	0.0353	0.139	7.20	2160.0
1750.0	0.03271	0.0333	0.583	1.715	3760.0
at maximum	0.0322	0.0322			

Applications of Brightness Sensation Data.—The brightness sensation data such as is plotted in Figs. 1 and 2 is at once applicable to engineering problems in glare, contrast and brightness. Intervals on the sensation axis correspond to intervals of objective brightness given by the ordinates to the curve at those points. In contrast glare, for example, contrasts in excess of 100 : 1 are excessive at ordinary intensities. This corresponds to 2 sensation units. At lower intensities 2 sensation units correspond to a considerably greater number of objective brightness units; *i. e.*, to a much greater ratio of intensities. Suppose, for

example, black letters are printed on white paper on the cover of a black lined box. The contrast is, say, 20:1 in brightness and 1.3 in sensation. If, now, the letters be cut away the contrast is 20:0 (∞) in brightness and only, say, 1.35 in sensation. Evidently contrast glare can only be properly dealt with in sensation units.

Another application of the brightness scale is in dealing with brightness glare. It is well known that the glare from a headlight that is intolerable at night is hardly noticeable at noonday. This is because the retina is very much less sensitive and the sensation scale tells us about how much less sensitive it is.

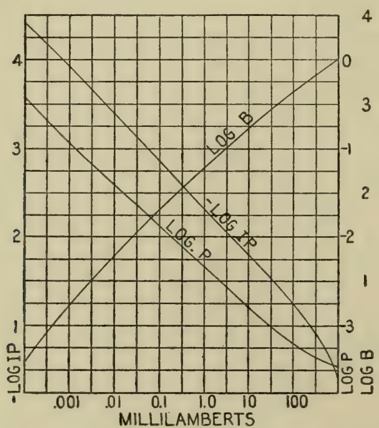

Fig. 2.—Threshold sensibility and brightness.

Illuminating engineers have to deal largely with four chief levels of brightness. To each corresponds a particular retinal sensibility and at each level certain contrasts and brightnesses are tolerable that are not at other levels.[4] These levels are:

	Mean brightness level ml.	Perceptible percentage difference	Threshold ml.	Relative sensibility Contrast	Relative sensibility Threshold
1. Exterior daylight ...	1000	0.0175	0.35	1	1
2. Interiors in daylight	10.0	0.030	0.017	59	21
3. Interiors at night ...	0.1	0.123	0.0014	1430	251
4. Exteriors at night...	0.001	0.79	0.00011	22300	3090

The table indicates, for example, that a sign board is as legible at night with 1/22,000 as much illumination as in broad daylight,

[4] General Report on Glare, TRANS. I. E. S., p. 987, vol. X, 1915.

while dimly illuminated objects are as visible at night out-of-doors as when the retina is adapted to a brightness 3,090 times as great in broad daylight. Many similar instances might be cited.

We have given data on both threshold and contrast sensibility at all brightness levels. A third sensibility, that determined by the brightness which appears excessive, would be of interest but this has yet to be determined.

Rate of Increase of Sensibility.—The rate at which the retinal sensibility increases has been studied by Nagel[5] and recently by the writer on a number of subjects. The usual method is to enter a dark room and note the time at which a surface of given brightness just becomes visible. The threshold drops to 10^{-4} in the first two or three minutes, then more and more slowly for hours.

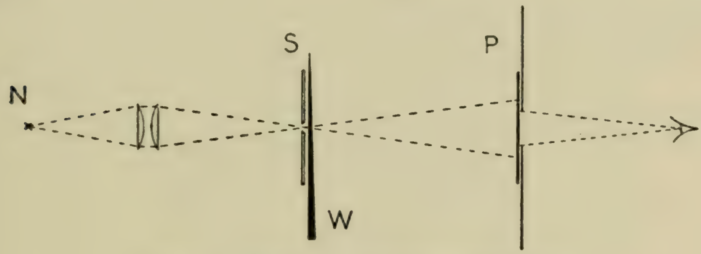

Fig. 3.—Apparatus for threshold investigations.

We have obtained considerable data of the same nature as Nagel's but for a number of different observers; with the simple and precise instrument used one is able to obtain the curve in seconds down to two seconds and then the instantaneous threshold values, all with the eye initially adapted to any desired brightness.

The image of a Nernst lamp (N) falls on a slit (S) then the beam spreads and illuminates a spot on a plate of solid opal glass (P). Intensities are controlled by sliding a black wedge W past the slit in machined metal ways. The wedge has a transmission varying by 0.40 per cm. of length and is provided with a millimeter scale. The front face of P is a large sheet of white cardboard with a hole cut opposite the illuminated spot of opal glass.

[5] Nagel cf. Helmholtz, *Phys. Optik*, 3rd. Ed., Vol. II, p. 264.

This card is illuminated by a lamp to the rear of the observer who faces the card at about 15 in. distance. Both field and spot brightness are constantly checked with a brightness photometer. Readings were taken both with and without an artificial pupil.

Much depends upon the recent history of the eye (even several hours back) as well as upon the initial state of adaptation. A person who has worked much in a dark room "gets his eyes" much more rapidly than one who does not but his final maximum sensibility is no higher—somewhat lower according to data so far accumulated. From curves run in the afternoon we could tell at once whether a given subject had worked in a dark room during the forenoon.

Retinal light persists for only 10 to 20 minutes when one has

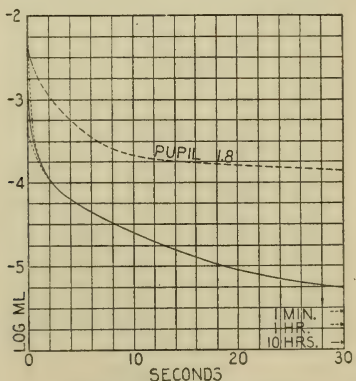

Fig. 4.—Rate of adaptation.

recently been in darkness and then in a dimly lighted room but persists for fully an hour when a subject has just been in bright sunlight for some time. Initial adaptation influences only the initial slope of the adaptation curve. Our standard initial adaptation was that corresponding to a brightness of 0.1 ml.—about the average of objects in a moderately lighted living room at night.

Data are given in the following table and Fig. 4 for about an average eye (the writer's) initially adapted to 0.1 ml. for about 10 minutes. The neutral absorbing wedge (W, Fig. 3) was moved slowly along at such a rate that the test spot was just visible. Scale readings were taken at intervals by an assistant. The full curve is for initial adaptation 0.1 and the eye pupil, the dotted

branches for initial adaptations of 2.8 and 0.032 ml. The dashed curve is for the same eye through a fixed artificial pupil of 1.8 mm. diameter.

Time	Eye pupil Ml.	1.8 mm. pupil Ml.
0 sec.	0.00131	0.0044
1 "	0.00019	0.0020
2 "	0.000111	0.00122
5 "	0.000054	0.00044
10 "	0.000027	0.00021
20 sec.	0.0000088	0.00016
50 "	0.0000031	0.00011
1 min.	0.0000028	—
1 hr.	0.0000014	—
10 hrs.	0.0000012	—

Size of Pupil.—In normal eyes the pupil contracts automatically to protect the retina from excessive brightness and expands to admit more light to the retina when required. The diameter varies from about 2 to about 8 mm. On sudden exposure to a

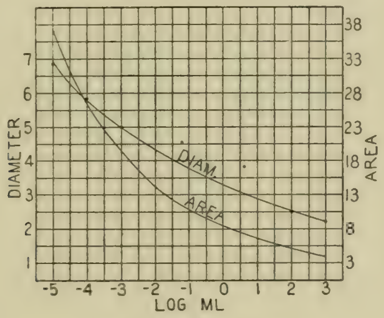

Fig. 5.—Size of pupil.

brighter light, the pupil contracts in about one second, on suddenly lowering field brightness it expands to about 5 mm. in about two seconds and then continues to expand slowly to the limit. Even in the stationary state the pupil is constantly enlarging and contracting with a range of half a millimeter or more and an irregular period of from a half to two seconds.

We have obtained data showing the equilibrium sizes of pupil corresponding to each brightness of field viewed. The apparatus required is very simple—a flat piece of metal in the form of a very slender V, tapering from 10 mm. to 1 mm. in about 9 cm.

When this is held just in front of the eye, an umbra and penumbra are seen. It is advanced until the umbra reaches the point of view, then some convenient cross arm (the finger nail is sufficiently exact on a slender wedge) used to mark the height of the visual axis and the width read at that point. Data are given in the following table and curve.

SIZE OF PUPIL AND BRIGHTNESS.

Brightness (log)	—5	—4	—3	—2	—1	0	+1	+2	+3
Diameter	6.9	5.8	5.0	4.3	3.8	3.3	2.9	2.5	2.2
Area	37.4	26.4	19.6	14.0	11.3	8.5	6.6	4.9	3.8

Brightnesses are in log millilamberts, diameters in millimeters and areas in square millimeters. Each of two observers obtained diameters about 0.5 mm. in excess of that corresponding to the smoothed curve shown at 0.1 and 1.0 ml., indicating that at ordinary working brightnesses the pupil is abnormally large. From the extreme areas (37.4 and 3.8) it is seen that size of pupil can affect retinal sensation very little in comparison with the wide variation in sensibility of the retina itself.

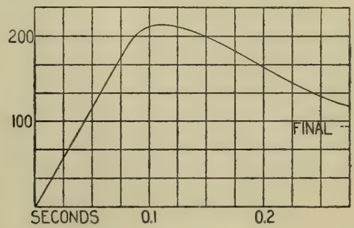

Fig. 6.—Growth of visual impression with time.

Rate of Decrease of Sensibility.—Near the threshold of vision, as Blondel[6] has shown, the visual impression (subjective brightness) is proportional to both intensity and time, hence to the energy falling upon the retina. When the eye is suddenly exposed to a bright white light, according to the data of Broca and Sulzer,[7] the impression rises to a maximum in about 0.1 second then decreases to a final value, about half the maximum value, after about 0.4 second (Fig. 6).

At lower intensities the maxima are lower and occur after a much greater lapse of time.

[6] Blondel and Rey, TRANS. I. E. S., Nov., 1912.

[7] Broca and Sulzer, *Comptes Rendus*, Vol. 137 pp. 944, 977, 1046, 1903.

Local Adaptation.—In determining the instantaneous threshold with a given initial adaptation, nearly the whole field of view was filled by the illuminated surface used to bring the retina to a given adaptation level. The following data were obtained to find the effect on the sensibility of the fovea of exposing the retina to illuminations of various sizes, locations and intensities.

When the whole field was illuminated to 0.1 ml. in brightness the instantaneous threshold was 0.0019 ml. The field was then limited more and more until finally it was reduced to a spot 1.5 mm. in diameter at 35 cm. distance (the size of the fovea is about 7½ deg. or 0.015 steradian), the outer part of the field being the

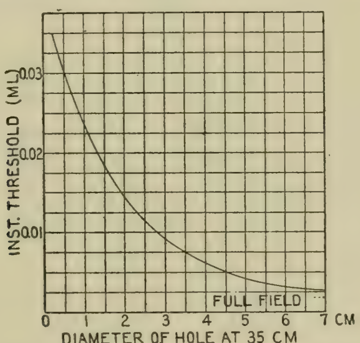

Fig. 7.—Local adaptation, 0.1 ml. field.

black interior wall of a 2-in. (5.08 cm.) tube. The remarkable result was obtained that as the field was stopped down with black, the threshold was *raised*; *i. e.*, the sensibility *decreased* whereas one might expect the lowering of the average illumination to increase sensibility.

Solid angle of bright spot	Instantaneous threshold Ml.
Full field	0.0019
0.43	0.0020
0.16	0.0028
0.016	0.0042
0.0058	0.0092
0.0026	0.0143
0.00065	0.0235
0.00016	0.0300
0.000041	0.034

The last reading is taken at an angle so small as to correspond

on the retina to a dot but 0.09 mm. in diameter (roughly 1/1000 the area of the fovea) and the curve is still ascending. It would appear that either (1) the reaction of but a few cones at the center of the fovea controls the sensibility level of the whole retina or else (2) the conflicting tendencies to light and dark adaptation in some way depress the sensibility of the whole retina.

A few readings were taken with brighter fields, 1 ml. and 100 ml. At 1 ml. the effect is just as pronounced as at 0.1 ml. but at 100 ml. the size of the bright spot had but little influence on sensibility.

Solid angle of bright spot	Instantaneous threshold Field = 0.1 ml.	1.0 ml.	100 ml.
Full	0.0019	0.0039	0.019
0.43	0.0020	0.0042	—
0.016	0.0042	0.0240	0.025
0.0028	0.0143	0.0355	0.020

A strong glare produced by a 25-watt ordinary tungsten lamp at an angle of 30° with the axis of vision was found *not* to depress the sensibility level very much (20 per cent.). The readings were duplicated when a frosted globe lamp was substituted for that with a plain globe first used.

The effect of introducing a black spot in the center of a light field was to *increase* sensibility in every case. At 100 ml. a large black spot doubled the sensibility. These results are such as might be anticipated if the light flux at the center of the fovea is what chiefly controls retinal sensibility.

Solid angle of black spot	Instantaneous threshold Field 0.1 ml.	100 ml.
0.00	0.0022	0.019
0.047	0.0011	—
0.25	0.0008	0.008

It has long been known that in illuminating a space exhibiting heavy contrasts, such as a machine shop, much more light and a higher brightness level are required than in lighting a room showing only very mild contrasts. Our observations recorded above suggest an explanation for this. In our case a central spot of fixed brightness was varied in size from the whole field of view down to a nearly vanishing point, with continually decreasing sensibility. In a room, therefore, where glare spots and dark shadows abound, we should expect a lowering of sensibility by

many times, not so much because of the bright spots as of the dark shadows: With a lowering of sensibility, of course, increased illumination is instinctively demanded. This and similar explanations might be given for numerous other well known phenomena if space permitted.

Relative Sensibility to Different Wave-lengths.—The most recent data on the relative visibility of radiation is that of Ives,[8] Nutting,[9] and Hyde.[10] The reciprocal of the radiant power necessary to produce a given light impression is taken as a measure of the relative sensibility to light of different wave-lengths. The latest accepted values are the means for 21 subjects and are probably not in error by more than 0.01.

Wave length	Visibility[9]	Wave length	Visibility[9]	Wave length	Relative visibility[10]
0.40	0.002	0.55	0.995	0.63	280.0
0.41	0.003	0.56	0.993	0.64	170.0
0.42	0.008	0.57	0.944	0.65	100.0
0.43	0.012	0.58	0.851	0.66	53.0
0.44	0.023	0.59	0.735	0.67	27.0
0.45	0.038	0.60	0.605	0.68	13.0
0.46	0.066	0.61	0.468	0.69	6.3
0.47	0.105	0.62	0.342	0.70	3.2
0.48	0.157	0.63	0.247	0.71	1.6
0.49	0.277	0.64	0.151	0.72	0.79
0.50	0.330	0.65	0.094	0.73	0.39
0.51	0.477	0.66	0.051	0.74	0.19
0.52	0.671	0.67	0.028	0.75	0.095
0.53	0.835	0.68	0.012	0.67	0.045
0.54	0.946	0.69	0.007	0.77	0.020
		0.70	0.002		

Between wave-lengths 0.48 and 0.67, visibility is closely represented by the formula

$$V = V_m R^a e^{a(1 - R)}.$$

in which $R = \lambda max/\lambda$ and $a = 181$, λmax being 0.555μ. Recently, Ives[11] has written for visibility the sum of three terms similar in form to the above corresponding to the three primary sensation curves. The terms representing the red and blue sensations are,

[8] Ives, *Phil. Mag.*, Dec. 1912.

[9] Nutting, TRANS. I. E. S., p. 638, 1914.

[10] Hyde and Forsythe, *Phys. Rev.*, p. 70, July 1915.

[11] Ives, TRANS. I. E. S., p. 316, 1915.

of course, very much smaller than that representing the green sensation.

Absolute Sensibility of the Retina.—Ives[12] has made a careful determination of the ratio of the light unit (the lumen) to the energy unit (the watt). He finds 1 lumen = 0.00162 watt of radiation at the wave-length (0.555μ) of maximum visibility and at other wave-lengths in proportion to the relative visibility as given above.

At first thought it would appear that this ratio should be a measure of the absolute sensibility of the retina and should vary with the subject making the determination and with a given individual according to his retinal sensibility level. A given il-

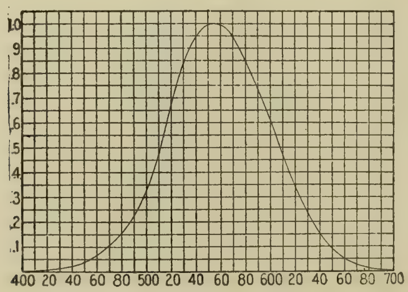

Fig. 8.—Relative wave-length sensibility.

luminated surface undoubtedly appears many times brighter at one time than at another. The reason that the ratio of the lumen to the watt is invariant is that the lumen itself is invariant, being defined in terms of the luminous flux from a given set of standards and in no way dependent upon any sensation except that comparisons are made by a visual null method. A closely analogous case would be the determination of the relative weights of a commodity and a standard weight by the muscular effort of lifting. The determination of equality would be independent of the strength of the observer and of the sensation of weight felt by the observer so long as the weights were invariant during the comparison.

An absolute determination of retinal sensibility appears to be

[12] Ives, Coblentz and Kingsbury, *Ph. Rev.*, p. 269, April, 1915.

quite impossible since sensations can only be quantitative compared with similar sensations by an equality method.

Hue Sensibility.—Sensibility to differences in wave-length varies considerably throughout the spectrum and individuals differ widely from each other. Sensibility is greatest (least perceptible differences are smallest) at two places in the spectrum, at about wave-length 492 in the blue-green and at 581 in the yellow-orange. Many persons can just distinguish the difference in hue between the two sodium lines 589.0 and 589.6μ.

Data on 12 subjects taken by Steindler[13] and reduced by the writer together with more recent data by the writer and L. A.

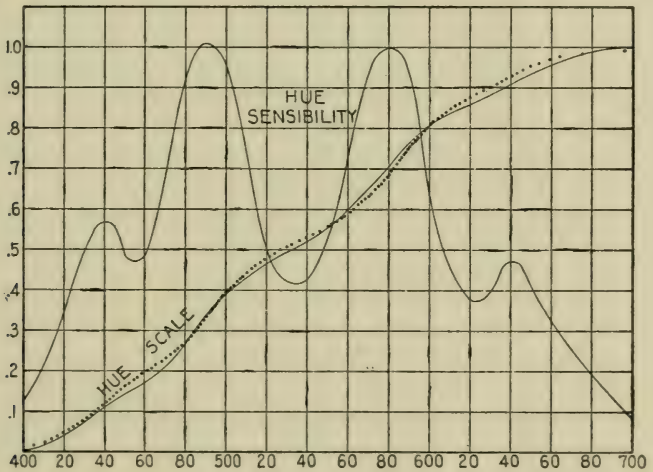

Fig. 9.—Sensibility to wave-length differences.

Jones on six subjects give the data of the following table and figure as means:

	Wave length $\mu\mu$	Perceptible difference $\mu\mu$
First minimum	440	2.47
First maximum	455	2.93
Second minimum	492	1.36
Second maximum	534	3.34
Third minimum	581	1.39
Third maximum	621	3.75
Fourth minimum	635	3.00

As with other scales (v. s.) the integral of the hue sensibility is the hue scale. The integral of the hue sensibility curve given

[13] Steindler, *Wien. Sitz., IIA*, vol. 115, pp. 1–24, 1906

by the above data and curve is shown by the wavy diagonal curve in Fig. 9 and the following data. The scale unit is, of course, arbitrary; it is hue taken so that the entire spectrum from violet to red is comprised in ten units.

Hue scale	0	1	2	3	4	5	6	7	8	9	10
Wave-length ..	396	421	468	485	501	532	560	577	598	635	700

Equal differences on the hue scale correspond to equal apparent differences in hue and the curve gives the corresponding differences in wave-length. There are in all about 180 just noticeably different hues in the spectrum from red to violet and roughly 20 more from violet to red through purple. Mr. Jones and the writer have succeeded in actually stepping off the scale in just noticeably different steps experimentally. Mr. Jones' data are shown in the dotted line of Fig. 9, each dot representing an observation.

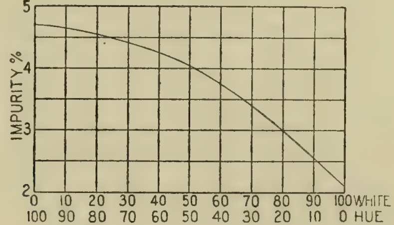

Fig. 10.—Sensibility to impurity.

The sensibility is nearly if not quite independent of brightness. As the hues are more and more diluted with white, hue sensibility decreases and the hue scale flattens out.

Purity Sensibility.—The amount of white that may be mixed with hues of various purities before it becomes noticeable has been determined by the writer and L. A. Jones. Data are given in the following table and in Fig. 10. The impurities are in percentages.

Per cent. white	0	10	20	30	40	50	60	70	80	90	100
Per cent. hue	100	90	80	70	60	50	40	30	20	10	0
Impurity noticeable ..	4.7	4.6	4.5	4.4	4.2	4.0	3.7	3.4	3.0	2.5	2.1

There are about 20 just noticeably different steps between pure hue and pure white.

I am indebted to Mr. L. A. Jones for data on hue and purity sensibility, and to Mr. Felix A. Elliott for valuable assistance in obtaining and reducing the data on brightness sensibility.

DISCUSSION.

Dr. P. W. Cobb: I think this paper is most interesting by reason, perhaps more than anything else, of the range of subjects that it takes up. In fact, it is a little bit difficult to discuss on that account, because I think any one of these subjects would require a good deal of thought for one to get it clearly in his mind.

In regard to the first problem taken up; the first attempt, I think, that was ever made to express sensation as a quantity, was by what is known as Fechner's formula, based on Weber's law. The latter states that the least perceptible increment in stimulus is a constant fraction of the stimulus itself. A further assumption underlying the Fechner formula is that the least perceptible increment in sensation is a constant unit in sensation.

Now these data of Koenig's show that the first assumption is correct only in a limited way; and whether one can consider the least perceptible difference in sensation as a unit is, I think, held to be an open question. But no doubt such a formula as Dr. Nutting gives on the third and fourth pages of his paper would give a more nearly equal difference in sensation for equal differences on the sensation scale than would simple equality of brightness-ratio. That is to say, the contrast due to equal brightness-ratios in any two cases is, as he says, not equal for the two, depending on the absolute intensities considered. As he has shown here, too, the brightness considered as the integral of the sensibility is different according to the criterion which one takes for sensibility. I think probably there are other differences. Koenig used an artificial pupil. I do not understand that Dr. Nutting did.

Dr. P. G. Nutting: Yes, I did.

Dr. P. W. Cobb: Then there is the fact that different eyes are different in this respect. It would seem though, if it is the case that the formulas are different here, that one would have to be somewhat guarded in how one accepts these sensation-values as final, although perhaps for rough estimates of allowable contrast they may be perfectly legitimate.

In connection with the instantaneous threshold, I was very much interested in the results that Dr. Nutting obtained, especially in showing the effect on this threshold of variations in the size of

the initial field: the fact that when the initial bright spot was smaller and of the same brightness, the threshold fell out larger; and the contrary case, where he put a black spot in the center of the bright field, that the threshold decreased with increase in the size of the black spot. It would be difficult to explain that; in fact, one might theorize on it a great deal without coming to any conclusion.

One more word in connection with the threshold question; it has been found that a threshold is different according to the size of the field that is used in the test, and I am inclined to the opinion that the simple specification of brightness should be accompanied by specification of the size, in angular measurement, of the test-field used.

In regard to hue sensibility, the figure at the top of the sixteenth page shows, on a hue scale, ten divisions for the entire spectrum. Dr. Nutting made some remark in which he included the region from blue or violet back to red through the purples. I forget how large the interval was that he attributed to that portion of the color scale, but the thing that strikes me is that one would have arrived back at the orginal hue, that is, at red, which is again zero on the scale, and, of course, when one gets to that point, there is in fact no difference, but according to his scale all the difference possible. For that reason I feel that perhaps the disposition of the results in that way might be misleading. If one goes in one direction, through the purples, the blue is nearer to the red by this measure than it is in going in the other direction through the spectrum; we have therefore to think of the hues as arranged—a circle, and of the hue difference as represented by the angular difference between two points thereon.

Mr. M. Luckiesh: I cannot recall any other sixteen pages in the Transactions that are more important to the lighting people than these sixteen pages. Those of us who have had the pleasure of being associated with Dr. Nutting on the Committee on Glare witnessed a great many applications of such data, but the value of such data lies in their application and in impressing upon practitioners the importance of applying these or interesting themselves in such data. Dr. Nutting mentions some applications; there are a great many incorporated in the Glare Committee's re-

ports* and inasmuch as there have not been such specific data given heretofore, it has been necessary to adopt certain limits as to contrast, etc., that are desirable or undesirable. I hope that Dr. Nutting, who has this subject so well in hand, will continue it and bring out something more on these applications and in that way interest the practitioner. I believe that in dealing with the fundamentals of vision he has a large part of illuminating engineering incorporated right here, at least the beginning of a great part of it. Brief consideration will show many applications of such data.

Eliminating entirely the question of glare it is of interest to consider certain conditions found in practise to which computations can be applied of a different nature than those ordinarily applied but which give valuable information concerning the ability to see. For instance I have observed a short flight of steps a hundred feet or more from a single street lamp. On looking down the stairs at night one sees a series of photometric fields. If the light source is so far away that the difference in the illumination or brightness of two adjacent surfaces is not at least 2 per cent. it will perhaps be impossible to distinguish the two steps when viewed from the upper side. In fact under practical conditions a difference in brightness of several per cent. is necessary for comfortable vision. Such computations merely involve the inverse square law and can be readily applied to street lighting design. The same discussion applies to an interior stairway lighted by a source at a considerable distance. I have noticed many such cases where computations would have revealed the undesirable condition. This is certainly one argument against an extremely great spacing of street lamps.

Some time ago I became interested in the importance of retinal adaptation in street lighting especially and devised an apparatus for studying the effects of different kinds of street lighting and of different speeds of the observer in walking or riding down the street. A white disk, upon which about twenty black sectors were painted varying from 1° to 20° and separated by white spaces, was rotated at high speed. Now a gradated series of gray rings could be seen separated by white rings. These gray rings varied in brightness from white to the maximum of 20° black. This

* Trans. I. E. S., Nos. 5 and 9, vol. x. 1915.

disk received light through a slowly rotating disk whose variable opening was such as to reproduce a given lighting condition on the street. By varying the speed of this latter disk the effect produced was similar to varying the speed of the observer. Of course, there are many other factors involved outdoors, but it seems worth while to study the effect of different systems of street lighting indoors by such apparatus and thus determine the importance of adaptation. These experiments were done several years ago and appeared promising, although they have not been carried further.

I wish to emphasize the importance of the Fechner coefficient or threshold brightness difference in lighting problems. Ordinarily this coefficient is given as about 1.6 per cent., but of course it varies with the lighting conditions. Probably a value from 5 per cent. to 10 per cent. will be found more nearly to the practical value under a great many conditions of lighting outdoors and in the industrial field especially.

MR. I. G. PRIEST: I notice on looking over your curve representing experimental data that its departures from the curve integrated from the sensibility curve are rather the widest at the minor minima. This would seem to indicate that there was perhaps some basis of fact in the assumption that those minima are not real. Do you think that your experimental data indicates the fact that the minor minima may not be real?

DR. NUTTING (In reply): Following the usual procedure, I will answer the last question first, because in this case it is the most abstruse. Mr. Jones finds these maxima more pronounced in his own vision than in that of the average person; he has indeed picked up still another one further out at the blue end. I think the departure there indicates that Mr. Jones has more pronounced maxima than the average person for which the curve is integrated. These small maxima in the blue and red are undoubtedly absent in the vision of some people, but there is no question but that they are present in a great many eyes, and probably in the average eye.

Now, in regard to the visibility of extreme red and extreme violet, I would suggest that the point is not at issue in the hue

sensibility curve. The curve flattens off there because there is less than one unit more of hue difference from there on.

Dr. Cobb raises a question regarding the sensibility data and the rate of adaptation; that particular data is the mean of, I think, seven different subjects. We regard that curve as quite well established. The criticism does apply, however, to a great deal of my other data since it was taken largely with but one or two subjects and must be regarded as preliminary, although tests of these eyes show that their properties are pretty close to the average. The question regarding the hue scale would not have arisen if the text had been explicit. The scale was reduced to 10 units there simply arbitrarily. Ten is as good as any other number, it being understood that the least perceptible steps are one twentieth of that; that is, there are for most eyes about 200 perceptible hue differences, whereas here we have ten steps arbitrarily taken. The unit of sensation referred to is simply that arising from the use of ordinary logarithms with constant of proportionality unity. That is, two sensation units would correspond to brightnesses differing by a factor of one hundred.

I left out one very important point which I can give in a sentence in regard to the depression of sensibility with contrast. Besides using this bright spot in the centre of the field, we tried a field half black and half of the original brightness. In this case the sensibility was not changed; in the rough experiment which we made, the sensibility for the divided field is nearly the same as for the bright half. This sort of contrast is then not very effective in depressing the sensibility.

(*Discussion of this paper is continued on page 131.*)

SIMPLE METHODS OF COMPUTING LIGHT FLUX AND HORIZONTAL ILLUMINATION.

BY W. E. HODGE AND R. W. CHADBOURNE.

Synopsis: This paper describes a simplified method of computing the light flux from a lamp, using the vertical distribution curve. The curve is divided into 10° angles and the flux is found for each angle by means of a special device described. No figuring is necessary except addition. It also describes a method of finding horizontal illumination. Only two simple slide rule computations are required. This is done by means of a special curve which can be taken directly from the vertical distribution curve without any figuring.

In connection with their work the writers have developed a few simplified methods of solving certain illuminating problems. The two more practical methods are outlined herewith.

FLUX CALCULATION.

The first method has to do with the computation of light flux from the vertical candlepower distribution curve.

It is a well known fact that the total value of the light flux emitted in any zone is given by the formula:

$$\Phi = 2\pi I\ (\cos\theta_1 - \cos\theta_2)$$

where I = mean candlepower for the zone and θ_1 and θ_2 are the limiting angles measured from a vertical axis. There are several methods of computing this value, most of them requiring either the construction of a special diagram or the computation and addition of several different quantities. One of the simplest is to divide the curve into 10° angles, take the reading at the middle point of each, multiply it by $2\pi\ (\cos\theta_1 - \cos\theta_2)$ for the zone, and add the results thus obtained. The method under discussion is a development of this method using a special device for making the computations. The device is shown in Fig. 1.

The values of $2\pi\ (\cos\theta_1 - \cos\theta_2)$ for all the 10° zones from 0° to 90° are laid off to a convenient scale on a horizontal axis AB, and ordinates are drawn through these points. The diagram

* A paper read at the mid-winter convention of the Illuminating Engineering Society, New York, February 10, 11, 1916.

is divided vertically into equal sections of the same magnitude as those on the polar co-ordinate paper on which the candlepower curves are drawn. At the point M, at a distance from A equal to unity, the ordinate MN is constructed. If now a straight-edge

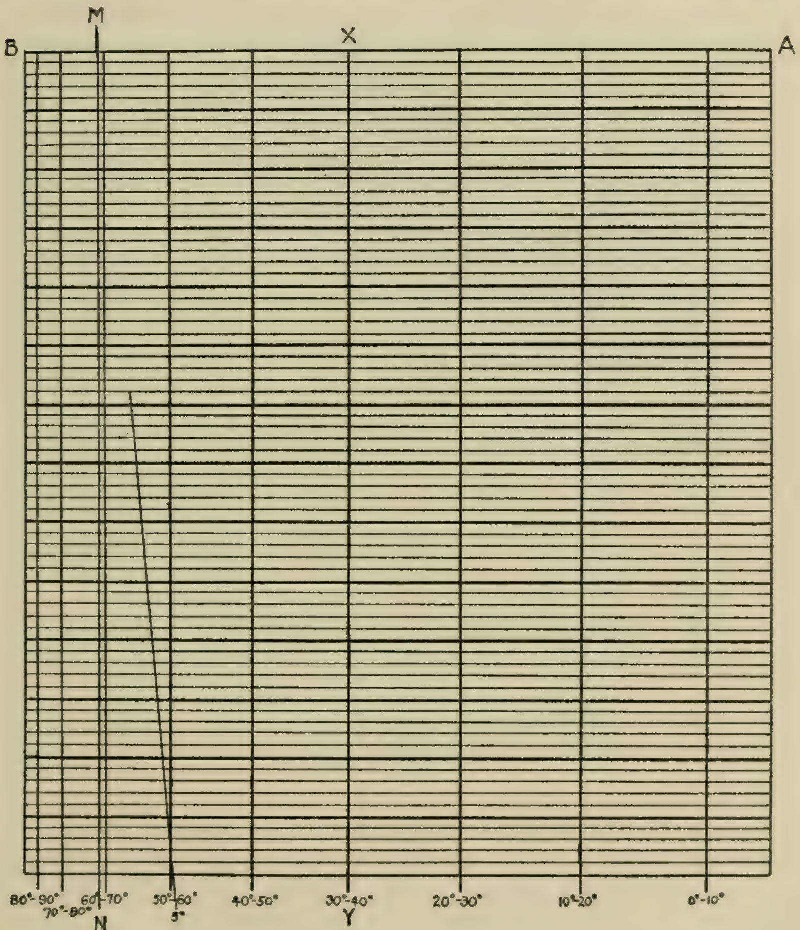

Fig. 1.

be swung about the point A as an axis, it is evident that the distance intercepted on any ordinate XY is to the distance intercepted on the ordinate MN as AX is to AM. But $\frac{AX}{AM} = 2\pi\ (\cos\theta_1 - \cos\theta_2)$, since AM is unity. If then there be inter-

cepted on MN an amount equal to the mean candlepower for the zone in question, the distance intercepted on XY will be $2\pi I (\cos\theta_1 - \cos\theta_2)$, or will represent the luminous flux of that zone.

In practise, the diagram is best constructed on a thin piece of transparent celluloid. A narrow strip of the same material is pivoted at A, and cut so that its edge, projected, intersects A. The diagram is laid upon the vertical candlepower distribution curve so that M coincides with the origin on the curve sheet, and the two are fastened together at this point with a thumb tack. Suppose that it be desired to find the flux from 0° to 70°. The diagram is swung about on the curve till MN coincides with the 5° line. If the polar co-ordinate paper has no 5° divisions, a line may be drawn on the diagram so as to make an angle of 5° with MN. The diagram is then swung so that this line falls on the 10° line of the polar curve sheet. The straight-edge is swung around till it crosses MN at the same point as the candlepower curve, it being assumed that this value of the candlepower is the average for the 0° —10° zone. The intercept by the straight-edge on the 0° —10° ordinate then represents the lumens in the 0° —10° zone. This is repeated for the other 10° zones up to 70°, and the results for the separate zones are added together.

It might be thought that the assumptions made regarding the mean candlepower of the 10° zone would lead to some considerable error, but for the curves usually encountered in practise, if the zone being measured is large, the likely error of the method is considerably less than the likely error of the curve on which it is used.

It has been found very convenient to have on the diagram a second set of lines giving the values for 5° angles so that where-ever the curve is changing rapidly the values can be taken off for each 5° zone. These lines were omitted in Fig. 1 for the sake of clearness.

This graphical method possesses the great advantage of requiring no slide rule, table of cosines, or drawing materials of any sort. No calculation beyond a simple addition is involved. The diagram is direct-reading for all candlepower curves plotted on sheets having the same size of co-ordinates, no matter what the

scales of the curves, as the candlepower scale is the vertical scale of the diagram. Furthermore, the calculations for all zones are equally simple,—and so simple that after a little practise with the diagram, an operator can show surprising speed.

HORIZONTAL ILLUMINATION CALCULATION.

A second method has to do with the computation of horizontal illumination. Referring to Fig. 2, A is a source of light at a height H. B is a point at a horizontal distance D from A. The horizontal illumination at B is given by the formula :— $E = \frac{I \cos^3 \theta}{H^2}$ where I = candlepower intensity at angle θ. It can be seen that for all points on AB, θ is a constant, and therefore $I \cos^3 \theta$ is a constant. From this it follows that $E = \frac{I}{H^2} \times$ a con-

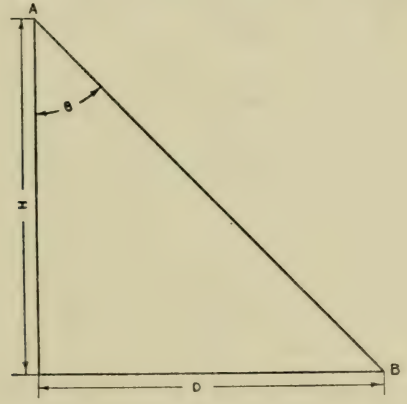

Fig. 2.

stant. Since $\frac{D}{H} = \tan \theta$ it must follow that this value at once determines $I \cos^3 \theta$. If, therefore, a curve be plotted giving the value $I \cos^3 \theta$ for different values of $\frac{D}{H}$ it will enable one rapidly to compute the horizontal illumination at any point. It is necessary merely to find the ratio $\frac{D}{H}$, read the value $I \cos^3 \theta$ from the curve and divide this by H^2.

In Fig. 3 is reproduced such a curve developed from the candlepower distribution curve shown in Fig. 4.

Example:—Assume the lamp supported at a height of 15 ft.
(1) What and where is the maximum illumination?
(2) What is the illumination 35 ft. from the base of the pole?
(3) Where is the illumination 0.5 foot-candle?

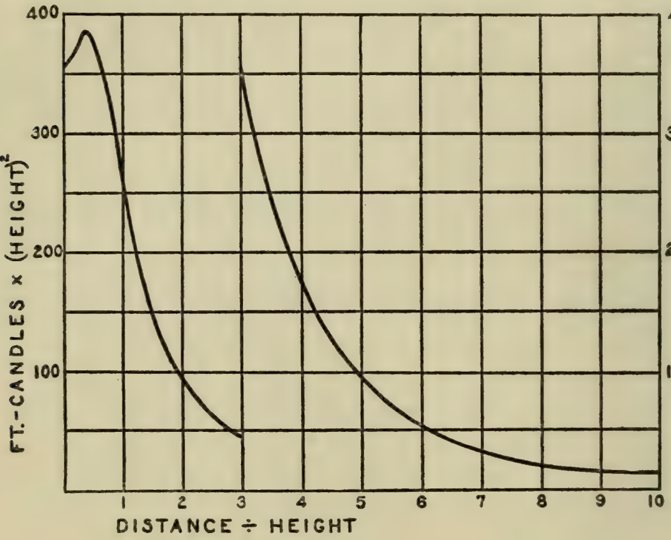

Fig. 3.

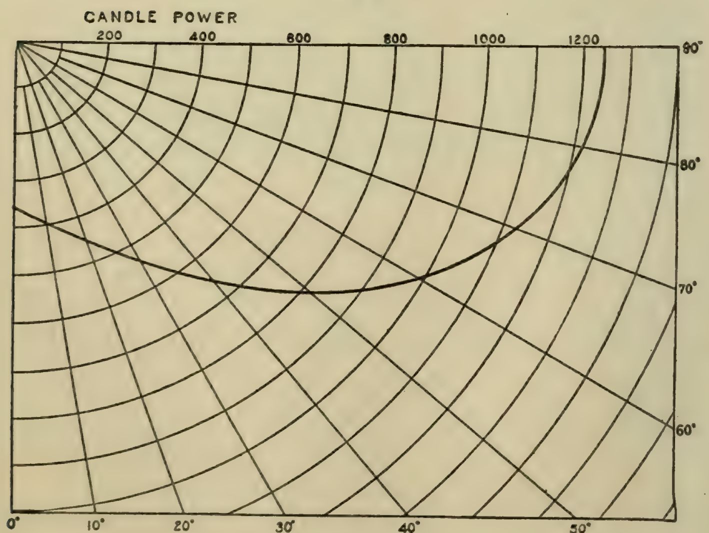

Fig. 4.

Solution:—(1) From Fig. 3, it is seen that the maximum occurs at the value $\frac{D}{H} = 0.4$; therefore $D = 6$. At this point the curve reads 380 therefore the horizontal illumination $= \frac{380}{15^2} = 1.69$.

(2) At 35 ft. $\frac{D}{H} = 2.33$; at that point the curve reads 78 and hence the horizontal illumination $= \frac{78}{15^2} = 0.347$.

(3) At the point where the illumination $= 0.5$ foot-candles the curve must read $0.5 \times 15^2 = 112.5$. Referring to the curve it is seen that when $\frac{D}{H} = 1.80$, $D = 27$ ft.

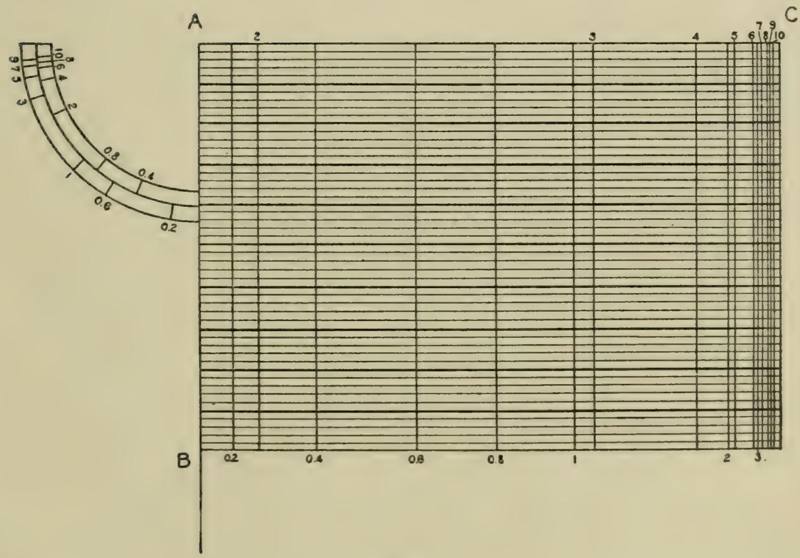

Fig. 5.

The computation of this curve is somewhat laborious unless some labor saving device be employed. It is necessary to determine several values of $\frac{D}{H}$, find the angle θ, read the value I for

that angle and multiply by $\cos^3 \theta$. This work can be very much simplified by the use of the device shown in Fig. 5. The values of θ for different values of $\frac{D}{H}$ are shown on the arc at the left. This enables one at once to place AB along the proper angle, determine the value of I and multiply it by $\cos^3 \theta$, using the same method as was used for computing lumens. The values for plotting, the curve can be read or taken off with dividers. It will be seen that there are two lines on the figures for 2 and 3. This is because it is generally necessary to change the scale at one or the other of these scales values. One scale is ten times the other. It can be seen that this device could be made to show directly the horizontal illumination curve for any chosen height. It can also be arranged to show either the vertical or the normal illumination.

AUTOMOBILE HEADLIGHTS.*

Synopsis: Causes of the excessive glare from headlights. Concentration of light in directed beams. Apparent brightness of source viewed from within a condensed beam. Brightness of flames and lamp filaments; tolerances. Minimum requirements in headlights and in road lighting; in side lights and signal lights. Visibility of lights. Minimum use of lights. Double lighting. Diffusing screens, color screens, shading screens. Directed lighting. Model regulations.

INTRODUCTION.

The extreme difficulty attending the regulation of the use of headlights is due to the difficulty of securing adequate road lighting without presenting an intolerable glare to persons facing the headlight. In searchlights and lighthouses, illumination alone is required, in locomotive headlights glare must be considered, while with automobile headlighting the appearance of the headlight from in front is of great importance compared with its usefulness in lighting the road. Only by the application of a thorough knowledge of the causes of glare and of the requirements of headlighting may the best compromise of interests be effected.

If an image of a bright source of light be formed by a lens or mirror, then this lens or mirror if viewed from near the image point appears filled with light and of an intrinsic *brightness equal to that of the source.* In other words the light flux per unit area per unit solid angle in the direction of the lens axis is the same at the lens (or mirror) as at the source itself. This principle of dioptics is fundamental in treating of the glare from headlights.

This principle holds for lens alone or for mirror alone provided the mirror be so located (*i. e.,* with source at focus) that it throws light forward, not back upon the source. In the latter case (source at center of spherical mirror) the mirror merely serves to brighten the intensity of the source by from 20 to 90 per cent. according to the source and the nature and polish of the mirror. In this position it is used with a lens and the apparent brightness of the lens is that of the reinforced source.

* Report No. 11, Committee on Glare, I. E. S., 1914-15.

When such a lens or mirror system is viewed from a point nearer or farther than the image but near the axis, the lens surface appears as bright as when viewed from the image, but only the central zones of the lens appear bright since the light from the outer zones does not enter the eye pupil. If viewed from a point at one side of the axis, the same statement holds but the bright zone is no longer central with the axis. If viewed from a point outside the cone, of course no light is seen except such as is scattered by dirt or irregularities on or in the lens itself.

When such a directed beam is photometered by placing a white photometer screen in and perpendicular to it, the brightness of this screen is what is measured by the photometer. This brightness is proportional to the light falling on the screen, hence to the flux density at the screen or to the total flux of light through the lens and to the ratio of the area of cross section of the beam at the lens to its area where the photometer screen is placed. This follows from the fact that the total flux of light through the cone of illumination is constant. In other words, the photometered brightness of the beam varies approximately as the inverse square of the distance from the image point. This brightness is proportional to that of objects illuminated by the beam and has no relation to the apparent brightness of the lens when viewed from within the beam. Consider two special cases:

When the beam is divergent, the image of the source is virtual and behind the source. The photometric brightness follows approximately the inverse square law since the cross section of the cone of light varies inversely as the distance from the apex, that apex being not the lens, mirror or source but the image of the source thrown by the lens or mirror. On the other hand, the brightness of the image to the eye is that of the source. Similarly, if the beam converges to an image in front, the inverse square law again holds approximately for photometric brightness, distances being measured to the image if the image is small, to some arbitrary point near it if large.

These two laws—visual brightness equal to that of the source itself, photometric brightness inversely as the square of the distance from the image—hold exactly only with ideal systems, in practical cases various causes lower both kinds of brightness;

imperfections in lenses and mirrors scatter light irregularly, spherical aberration lowers intensities near the boundaries of zone pencils, coma near the edge of field pencils of the light beam; mirrors fail to reflect all the light while lenses both absorb light and reflect a small percentage out of the principal beam. Parts of the source are always more or less out of focus and at a distance atmospheric absorption is not negligible. These various departures from perfect systems are so small and so irregular that it would be useless to go farther into their nature. They cause departures of the order of 10 to 20 per cent. from the ideal case.

GLARE CONDITIONS.

Aside from the actual visual brightness of a headlight, another powerful factor in the glare it causes is the dark adaptation of the eye. The same headlight that produces an intolerable glare on a dark road is hardly noticeable at midday and not nearly so glaring on a brightly lighted thoroughfare as on an unlighted road. The slight adaptation caused by the glare itself is too late and too small to be of any service in reducing the glare but causes a decided loss of seeing ability immediately afterward, the effect lasting half a minute or more. This subjective factor, being beyond our voluntary control, cannot be made use of to reduce glare. Visual sensibility is fully a million times as great after a half hour's rest in darkness as in broad daylight.

Relative retinal sensibility at different brightness levels is approximately as follows:

	Mean brightness level ml.	Difference sensibility	Threshold ml.	Relative sensibility: Threshold	Relative sensibility: Contrast	Relative sensibility: Glare
Exterior daylight ..	1,000	0.018	0.35	1	1	1
Interiors in daylight	10	0.030	0.017	20	60	200
Interiors at night ..	0.1	0.123	0.0014	250	1,400	18,000
Exteriors at night..	0.001	0.79	0.00011	3,100	22,000	160,000

On well lighted downtown streets, the brightness level is fully 0.1 millilambert while the brightness of white paper normal to full moonlight is only about 0.003 millilambert and the limit of vision 10^{-6} millilamberts. The table shows what enormous variations occur not only from one level to another but between sensibility to glare to small contrasts and to the minimum required to see anything at all.

On unlighted roads there are three chief levels of brightness to be considered: (1) glare of headlights, (2) the roadway lighted by headlights, and (3) darkness near the threshold of vision. Complete or nearly complete darkness for a quarter of a minute or more brings the retina nearly to its maximum sensibility. The lighted roadway has a brightness of the order of 0.01 to 0.1 millilambert and brings retinal sensibility down to about 1/10 its maximum value. The brightness of approaching headlights is from 5 to 500 lamberts while that of white paper in full sunshine is about 10 lamberts. This brightness is sufficient to cause a bright after image as well as to lower sensibility.

The rate of adaptation is much greater the greater the interval from light to dark or from dark to light over which the change extends. We have no data on the extreme changes from headlight brightness to darkness but experiments with a brightness of 25 millilamberts (roughly 20 foot-candles on white paper) and complete darkness give results as follows: In one case the eye was accommodated to this brightness then the light suddenly switched off and threshold sensibility readings taken. In the other case the eye was adapted to darkness then exposed to this brightness.

	Sensibility change	
Time of adaptation	Light to dark	Dark to light
1 second	2.1 times	1.6 times
2 seconds	4.2 "	2.6 "
5 seconds	16.2 "	7.6 "
10 seconds	58.0 "	14.4 "
10 minutes	120.0 "	20.9 "

The limit of brightness to just not cause a blinding for an eye adapted to the darkness of night is about 0.1 lambert viewed steadily, about 0.3 lambert for an object in the field but not viewed directly, and perhaps 20 lamberts for an object flashing by the axis of vision.

When a steady, very bright light is at one side of the axis of vision the depression of the sensibility on the axis is quite marked until the light is at an angle of over 40°. The following data refer to a frosted tungsten 100-watt lamp and a field brightness of 0.1 millilambert:

Angle	0	10°	20°	30°	40°	No. lamp
Relative sensibility	0.11	0.17	0.26	0.42	0.65	1.00

Glare increases with the square root of the candlepower of the glaring light irrespective of the solid angle subtended by the glare unit. If glare be measured by the fractional increase in illumination of test field $(B - B_0)/B_0$, is glare. This law has been tested for lamps at a fixed angle of about 10° from the axis and found to hold, though a logarithmic relation would probably be as suitable.

REQUIREMENTS FOR THE USE OF HEADLIGHTS.

Minimum Requirements.—Adequate road lighting with ordinary headlights without blinding glare being out of the question, one or all of three possible compromises may be affected:

1. Reduce the source to the absolute minimum required and endure the remaining glare.

2. Design the headlight for maximum useful lighting with minimum glare and tolerate unavoidable and accidental glare due to road inequalities, or

3. Extinguish headlights or dim to mere signal lights temporarily on meeting travelers.

Regarding the first expedient, the minimum road illumination of service, if well distributed, is about that of moderate moonlight or 0.1 meter-candle. If limited to a spot the diameter of the width of the road or less, from ten to a hundred times this is required, say ¼ candle per square meter or 10 to 20 candlepower at the source. The brightness of any ordinary glow lamp or gas flame of this power is far in excess of the limit of tolerance.

The design of headlights to give maximum road illumination with minimum glare has received considerable attention by manufacturers and by the makers of city ordinances. The conditions for minimum glare are (*a*) minimum surface brightness of the source itself (lamp filament or gas flame) and (*b*) the limitation of the beam to the surface of the road, as far as possible, by screens, by directing the beam downward or similar means. Maximum effective road illumination is secured (in directed beams) by having the light flux in any cross section of the beam a maximum. The brightest spot on the road would be secured by having the light concentrated in a narrow beam, but for best seeing it is better to have a greater spread of the same light or,

as stated, the best illumination is measured by total flux rather than flux density.

These conditions for best illumination are not entirely incompatible with those for least glare. The same beam flux may be obtained with a large source of low brightness as with a concentrated source. Perhaps the most effective arrangement that is practicable is to enclose the source in a diffusing globe, lens and mirror being focused on the surface of this globe instead of on the source within.

Increasing the diameter of the headlight lens and focal length in proportion does not affect either road lighting or glare. Using a plate of diffusing material instead of a lens or frosting the lens itself reduces the glare to perhaps a third but reduces the road illumination hundreds of times, so that it is ineffective on the whole.

A beam may be directed downward and to the right by setting the source upward and to the left of the axial focal point or by tilting the whole headlight downward and to the right. Opaque screens toward the rim of the lens are ineffective since they limit zone pencils and not field pencils in the beam. A headlight provided with a large displaced source assisted by a metal screen over the upper left hand quarter of its front surface should cause very little glare to any one passing on the left. Another means of partial screening as effective but less sightly consists in placing the headlight at the rear end of a short blackened tube. The proper dimensions may be easily calculated for any particular form of headlight. The walls of the tube, assisted by any desired screen over the front end, effectually limit the field pencil of the beam in any desired manner.

The third remedy for headlight glare has proven very effective in localities where it has been tried, in fact if properly used by everyone, even ordinary headlights would present no glare problem of any moment. The rules to be observed are the following:

1. Headlights to be extinguished when within a given distance (150 feet, at least) of an approaching vehicle.

2. No headlights to be used on lighted city streets nor in any localities where not absolutely required.

3. Every vehicle to be provided with signal lights on every highway during lighting hours.

Double signal lights are decidedly better than single on four wheeled vehicles. Single red rear and double white front signal lights are the rule for such vehicles. Probably double rear lights, a red left and green right, would be sufficiently advantageous to be worth adopting. The reflecting bulls-eye buttons are effective and useful on most occasions but are useless when the vehicle to which they are attached is turned at an angle or when the approaching vehicle is without headlights.

Signal lights should, of course, be distinctly visible at a moderate distance. Lights of but a fraction of a candle fulfil this condition on unlighted roads. On lighted city streets a brighter light is required and from a half to one candle is perhaps best. Since the function of a signal light is to be visible and not to illuminate it would appear advantageous to give it a distinctive form or color or both. Some form of small transparency might be made both pleasing and effective.

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BIBLIOGRAPHY.

General Report on Glare (No. 1), 1914-15. Trans. I. E. S., vol. x, 1915, p. 987.

Report No. 3 on Glare, 1914-15 (Beam Photometry). Trans. I. E. S., vol. x, 1915, p. 366.

Report No. 10 on Glare, 1914-15 (Effects of Glare on Vision). Trans. I. E. S., vol. x, 1915, p. 1000.

Cobb, Percy W.—Vision as Influenced by the Brightness of Surroundings. Trans. I. E. S., 1914, p. 394.

Woodwell, J. E.—Intrinsic Brightness of Sources. Trans. I. E. S., 1908, p. 573.

Cravath, J. R.—Brightness. Trans. I. E. S., 1914, p. 394.

Report on Locomotive Headlights, Amer. Railway Master Mechanics Assn. Circular N, 1913-14.

Haskell, Raymond.—Lighthouse Illumination. Trans. I. E. S., 1915, p. 209.

Minick, J. L.—The Locomotive Headlight. Trans. I. E. S., 1914, p. 909.

Sweet, Arthur J.—An Analysis of Illumination Requirements in Street Lighting. Jour. Franklin Inst., May, 1910.

INTERIOR ILLUMINATION.*

Synopsis: This report shows the practical application of some of the principles set forth in the general report on glare. Tentative figures are given indicating safe limits of practise for contrast of brightness within the range of vision in interior illumination to avoid the bad effects of glare. It is suggested that brightness calculations to show the probable brightness contrasts introduced might well supplement the useful illumination calculations now commonly made.

The general report on glare made by this committee sets forth certain definitions and fundamental principles relating to glare. It is the purpose of this report to show their application to the practical engineering of interior lighting. For the convenience of the reader, the definitions of glare tentatively advanced by the committee in the aforesaid general report are here repeated as follows:

Glare.—(1) Brightness within the field of view of such excessive character as to cause discomfort, annoyance or interference with vision. (2) Excess brightness of, or flux of light from, the whole or any portion of the field of view, resulting in reduced vision, fatigue or discomfort of the eye. (3) Light shining into the eye in such a way and of sufficient quantity as to cause discomfort, annoyance, or interference with vision.

It is obvious that the illumination of interiors should be arranged to avoid glare as herein defined. The brightness within the field of view must be so distributed as to avoid this effect. It is also evident that brightness within the field of view includes not only sources of light and their equipment of globes or reflectors, but also ceilings, walls, papers and desks. The engineer should take into account everything within the field of view.

The foregoing definitions of glare include three effects. It should be noticed that brightness conditions producing any one or two of the effects may be present alone, or all three may be in evidence. For example: interference with vision also commonly known as "blinding effect" from a bright lamp may not be measurable when the lamp is at an angle of more than 25 to 30 degrees from the center line of vision. But it has been well demonstrated that excessive brightness anywhere within

* Report No. 12, I. E. S. Committee on Glare, 1914-15.

the visual field, even though it be outside the blinding effect zone, may be decidedly annoying and fatiguing. As far as interference with vision is concerned, the engineer is not nearly as limited in the choice and placing of equipment as he is by the other two considerations of fatigue and annoyance.

In the practical lighting of interiors to avoid glare effects, it is essential to determine what contrast ratios in brightness of adjacent surface the eye can tolerate continuously without suffering any of the fatiguing or annoying effects of glare. While the experimental data is not perhaps as complete as might be wished, enough has been collected to set a tentative limit of good practise.

In sunlight out-of-doors, brightness ratios of adjacent surfaces (excluding, of course, the sun which is avoided by the eye) are usually not over 1 to 20 and generally much less. The largest contrast ratios are found on bright days in the contrast between surfaces in full sunlight and those in deep shadow. We know that the eye is adapted to ordinary outdoor conditions without suffering the effects of glare.

For indoor conditions, the data which we have on the effects of glare consist of measurements of brightness taken both in rooms where conditions are known to have been such as to produce glare effects from the complaints of the occupants and in other rooms where no such complaints have been made. We have also brightness measurements in rooms used in a limited number of tests made for eye fatigue by the Ferree method, under conditions which produced various amounts of eye fatigue.

A study of these data shows that usually where glare effects have not been observed the contrast ratios between the brightest surfaces within the range of vision and the surfaces immediately adjacent are not over 1 to 100. Of course, the contrast ratio taken in this case is that presented to the eye, or in other words the projected area or surface. For a tentative working limit for the present, after considering the observed facts with both natural and artificial lighting, it appears probable that the comfortable limiting ratio lies somewhere between 1 to 100 and 1 to 200 and preferably until we have more evidence, the contrast

in brightness of adjacent surfaces should be kept below the 1 to 100 ratio.

As an example, the practical effects of lifting contrast ratios to 1 to 100 or less in interior artificial lighting at the present time would be to limit the brightness of bowls and globes in locations where they must be faced continuously to an approximate value of 250 millilamberts (232 apparent foot-candles or 0.51 cp. per square inch) for rooms with light colored ceilings and walls and with horizontal working-plane illumination of 4 foot-candles. The real criterion, of course, is the contrast of the globe or bowl against its possible background, rather than any fixed value of bowl brightness without regard to its surroundings. Obviously, if the total light flux used in the room is increased, the brightness of bowls or globes may be increased in proportion without changing the contrast ratio. That is, if a given bowl in a given room with a given size lamp is within the safe ratio, an increase in the size of the lamp will not change the ratio. On the other hand, the changing to darker color of the surfaces against which the bowls or globes are seen would necessitate a reduction of the brightness of the bowls to keep within the safe contrast ratio limit.

With daylight, the brightness of the sky is to be dealt with and this can only be modified by shades or window glasses. Too great contrast between the sky brightness as seen through the window and the brightness of the window casing and surroundings in the room cause glare. The contrast will be most pronounced when the window surroundings receive but little light by reflection from the interior of the room. This is the case when the room is very deep in proportion to the window area or the ceilings, walls and floor are dark. This is one good reason for certain school building regulations which have been proposed and enacted from time to time requiring a minimum ratio of window area to floor area, although this is not the main reason for the regulation.

Diffusing glass should be avoided in the lower sashes of windows not only because it introduces a brightness nearly equal to that of the sky on an unaccustomed portion of the retina but also because of the contrast between the glass and the wall below

the window. Such diffusing glass in the lower window sash is especially objectionable where the window sills are low.

In office lighting, glare from paper and desk tops is to be especially guarded against. The general method of treatment is the same as that which assures freedom from excessive contrast of brightness in the general illumination scheme. The same methods which tend to eliminate glare from light sources and surroundings, also eliminate glare from paper. When the eye is shaded from excessively bright surfaces but the paper is not, as in the case of localized lighting with a shaded lamp, there is still likely to be considerable trouble as it is almost impossible to so locate an individual desk lamp as to avoid this glare.

It is recommended that hereafter more attention than formerly be given in the engineering of interior illumination to the calculation of brightness contrasts. Such calculations may well be made a part of the preliminary work just as the calculation of available, useful illumination has been for some time past.

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LIGHTING LEGISLATION.*

BY L. B. MARKS.

Synopsis: The present status of legislation regarding lighting is discussed with special reference to schools, factories and workrooms, tenement houses, streets, locomotive headlights, etc. Both daylight and artificial light are considered. Transcripts of statutes, laws and regulations in several states are given. The inadequacy and ineffectiveness of existing legislation is pointed out and the necessary elements that must be included in a workable law are discussed. Recommendations are made for federal, state and municipal legislation. The paper concludes with a summary of striking facts in lighting legislation.

The purpose of this paper is to discuss some phases of the present status of lighting legislation especially in the United States with a view to awakening interest in the need of better legislation looking to the conservation of eyesight, the preservation of health, the prevention of accidents and the improvement in the efficiency of utilization of light.

The criticism has often been made that we legislate too much and that the community would be better off if much of the existing legislation were removed from the statute books. This criticism hardly applies to lighting because the legislation on this subject on the statute books is so meager and scattered and apparently so seldom called for that no legislative bureau in the country has found it worth while to collate it. The scope of the term lighting as used above is limited to the consideration of *light* and *illumination* and does not include the consideration of the generation or distribution of electricity or gas for lighting, or the rates of charge, etc.

Notwithstanding the greatly increased brilliancy of modern lamps which renders them dangerous to the eyesight unless properly shaded, safeguarding the eyes of the public from this source of danger has received comparatively little attention in legislation.

Even the first electric lamps whose rays were quite tolerable to

* A paper presented at a meeting of the Philadelphia Section of the Illuminating Engineering Society, January 21, 1916.

the eye compared with what we have to-day, invoked the ire of Robert Louis Stevenson 35 years ago when, in commenting upon the unshaded electric lamp at the "Figaro" office in Paris, he states:[1]

> In Paris at the Figaro office, a new sort of urban star now shines out nightly, horrible, unearthly, obnoxious to the human eye; a lamp for a nightmare! Such a light as this should shine only on murders and public crime, or along the corridors of lunatic asylums, a horror to heighten horror. * * * That ugly blinding glare may not improperly advertise the home of the slanderous Figaro, which is a backshop to the infernal regions; but where soft joys prevail, where people are convoked to pleasure and the philosopher looks on smiling and silent, where love and laughter and deifying wine abound, there, at least, let the old mild luster shine upon the ways of man.

So far as lighting legislation is concerned the situation with respect to safeguarding the eyesight is much the same to-day as it was when Stevenson wrote the lines above quoted. It should be stated, however, that the lack of suitable protective legislation has been due in a measure to the lack of well defined and accepted standards in prescribing illumination.

It is a simple matter to enact laws in relation to lighting, but by no means a simple matter to enact *effective* laws. To secure effective laws there must be co-operation between (1) the employer; (2) the employee; (3) the technical lighting engineer. Proposed new lighting statutes should be submitted to public hearing before enactment into law in order that the law may represent the best judgment of all parties concerned.

The individual is entitled to devise and use his own lighting arrangements and to cater to his personal taste provided he does not interfere with the rights of his neighbors—the public.

The class of legislation considered in the following pages is that which directly affects the public and is most readily amenable to rules and regulations, as for example the lighting of schools, factories and workrooms, tenement houses, streets, etc. The controversy with regard to locomotive headlights has been before the public for many years and merits immediate attention. Finally the consideration of daylighting, especially in connection with city planning, is of paramount importance in formulating legislation for the welfare of the public.

[1] "A Plea for Gas Lamps" by Robert Louis Stevenson (written in 1881).

SCHOOL BUILDINGS.

New York.—The only reference to schoolhouse lighting in the statutes of the State of New York is as follows:

"All schoolhouses shall be properly lighted." (Sec. III, Educational Law).

Connecticut.—The only reference to schoolhouses in the statutes of the State of Connecticut is as follows:

"Every schoolhouse shall be properly ventilated." (Sec. 2142, Laws of 1902.)

No mention whatever is made of lighting.

Pennsylvania.—In Pennsylvania the statute requires all schoolhouses to be "properly lighted." It is further specified that:

Light shall be admitted from the left or from the left and rear of classrooms and the total light area must, unless strengthened by the use of reflecting lenses, equal at least 25 per cent. of the floor space. (Laws of 1905.)

In every school building the total light area must equal at least 20 per cent. of the floor space, and the light shall not be admitted thereto from the front of seated pupils. (Laws of 1911.)

Indiana.—The Indiana Sanitary Schoolhouse Law contains the following provisions:

Interior walls and ceiling shall be painted or tinted some neutral color, as grey, slate, buff or green.

All schoolrooms where pupils are seated for study shall be lighted from one side only, and the glass area shall be not less than one-sixth of the floor area, and the windows shall extend from not less than 4 feet from the floor to at least 1 foot from the ceiling, all windows to be provided with roller or adjustable shades of neutral color, as blue, gray, slate, buff, or green.

For left-handed pupils desks and seats may be placed so as to permit the light to fall over the right shoulder.

Blackboards shall be preferably of slate, but of whatever material the color shall be dead black.

The Indiana State Board of Health regulations contain the following provisions:

No classroom shall exceed 24 feet in width, with the ceiling not less than 12 feet nor more than 14 feet in height.

No window sash shall have more than four lights, and the tops of all windows shall be square. When the proximity of other buildings or a portion of the same building interferes with the proper lighting of a classroom, the light shall be properly projected and diffused by the use of prism glass.

When artificial lighting by means of electricity or gas is used the lights shall be placed near the ceiling and the lights deflected by proper shades toward the ceiling, either indirect or semi-indirect lighting being used.

Where the light in any classroom is from the north, the proportion of glass area to floor area should not be less than 1 to 5.

Louisiana.—In Louisiana the State Sanitary Code prescribes that—

Every schoolhouse must be lighted in such a manner as to minimize eye-strain.

Each room must contain of actual surface of glass in the windows not less than one-seventh of the floor space.

North Carolina.—In North Carolina the regulations set forth that—

The light should come from the rear and left side, or left side of the pupil only, and the glass surface should equal from one-sixth to one-fifth of the floor area of the room.

The windows should be set 3 or 3½ feet above the floor, and the window head should come within 12 inches of the ceiling.

Texas.—In Texas the Public Schools Act specifies that—

Window openings shall not come lower than 3½ feet from the floor and shall extend to within 6 inches of the ceiling.

The area of the window surface * * * shall not be less than one-sixth of the area of the floor space, and no part of the classroom in which pupils are seated or required to study shall be at greater distance from the window than twice the height of the top of the window above the floor, except in cases in which adequate skylights are provided.

The main light in all one-room schools shall come from the left of the pupils as they sit at their desks, and in all larger buildings this condition shall be approximated as nearly as architectural demands and the demands of ventilation will permit.

Vermont.—In Vermont the State Board of Health regulations prescribe that—

Buildings shall be so located as to secure the best of light. Particular attention must be given to this in villages where the schoolhouse is likely to be surrounded by other buildings.

The window space should be one-fourth of the floor space and must not be less than one-fifth. There must be no more space between the top of the window and the ceiling than is required to finish the building, and the window sill must be 4 feet from the floor.

The light must be arranged so as to fall upon the pupils from the left or left-hand back, never from the front.

There must be curtains of a gray or buff color for all windows—two to each window—hung in the center of the window so that either the upper or lower half or both can be shaded.

Blackboards shall be placed opposite windows, never between, and shall be of a dark, lusterless color.

Ohio.—The Ohio State Building Code contains the following provisions with regard to school buildings:

The height of all rooms, except toilet, play and recreation rooms, shall be not less than one-half of the average width of the room, and in no case less than 10 feet high.

The proportion of glass surface in each class, study, recitation, high school room, and laboratory shall be not less than 1 square foot of glass to each 5 square feet of floor area.

Windows shall be placed at the rear or left and rear of the pupils when seated.

Tops of windows, except in libraries, museums and art galleries, shall not be placed more than 8 inches below the minimum ceiling height.

The unit of measurement for the width of properly lighted rooms, when lighted from one side only, shall be the height of the window head above the floor.

The width of all class and recitation rooms, when lighted from one side only, shall never exceed two and one-half times this unit, measured at right angles to the source of light.

The candlepower of electric lamps shall not be less than the following, *viz.*:

Auditorium.................	1 cp. to 2½ sq. ft. of floor space
Gymnasium.................	1 cp. to 2½ sq. ft. of floor space
Stairways and hall..........	1 cp. to 4 sq. ft. of floor space
Class and recitation rooms..	1 cp. to 2 sq. ft. of floor space

In Ohio the law specifies that—

No wall of any building * * * used for lighting school or classrooms shall be placed nearer any opposite buildings, structure or property line than 30 feet.

It is to be noted in this last provision that no cognizance is taken of the height of the opposite building; therefore, the restriction as to thirty (30) feet distance from the opposite building may fail utterly of its purpose.

In this connection it is significant that in New York State there is a law to the effect that no liquor saloon shall be situated within two hundred (200) feet of a school building; but the statutes do not provide against the erection of a block of buildings 200 feet high directly opposite such a school building, thereby obscuring the daylight and sunlight from the school.

The Illuminating Engineering Society plans to issue a code of schoolhouse lighting in order to lay before school boards, archi-

tects, legislators and others who may be interested, authoritative information that will serve as a basis for statutes, ordinances, rules and regulations regarding the lighting of schoolhouses both by natural and by artificial lighting; and further, to assist those who may be charged with remodeling the lighting of existing buildings and designing the lighting arrangements of new buildings.

In a paper[2] presented before the Illuminating Engineering Society in 1915, the following recommendations were made as to light intensity and brightness in school lighting:

Natural Lighting.—Minimum illumination on desk top, 3 foot-candles. Diversity of illumination no greater than 100 to 1.

Artificial Lighting.—Highest permissible brightness, 3 candle-power per square inch when viewed against a light background. Minimum illumination on desk top, 2.5 foot-candles.

It is of interest here to note that a British committee representing the London Illuminating Engineering Society, the Association of Teachers in Technical Institutions, the London Teachers' Association and the Medical Officers of Schools Associations reported in 1913 in favor of the following standards of light intensity in the artificial lighting of schools:[3]

Artificial Lighting: (*a*) For ordinary clerical work (reading and writing, etc.), minimum illumination, 2 foot-candles.

(*b*) For special work (art classes, drawing offices, workshops, and stitching with dark materials, etc.), minimum, 4 foot-candles.

(*c*) For assembly rooms, etc., and for general illumination, minimum, 1 foot-candle.

Measurements on horizontal plane, 3 feet 3 inches above floor level.

In 1914 the same committee submitted recommendations for the daylight illumination of schools, an abstract of which is as follows:

Daylighting: No place is fit for use in a schoolroom when diamond type cannot be read easily by a normal observer at a distance of ½ meter (20 inches).

The darkest desk in any schoolroom should receive not less than 0.5 per cent. of the unrestricted illumination from the complete sky hemisphere.

[2] "Safeguarding the Eyesight of School Children," by M. Luckiesh. TRANS. I. E. S. vol. X 1915, p. 181.

[3] *Illuminating Engineer*, London vol. VI, 1913; p. 364.

[4] *Illuminating Engineer*, London vol. VII, 1914; p. 365.

The windows should be located in the wall to the left of the pupils, and the glass should be carried to the ceiling, and not interrupted by cornices, pillars or decorations.

No desk in a schoolroom should be farther from the window wall than twice the height of the top of the glass above the desk surface.

The ceiling should be white. The wall opposite to the window and the wall behind the children should be lightly colored from 30 inches above the desk level. The wall around or behind blackboards should be somewhat darker than the rest of the room.

All furniture, desks and surfaces in the lower part of the room should be finished in an unobtrusive color, dark shades and black being avoided.

In lighting a schoolroom, or for that matter any other interior, the adequacy and comfort of the illumination are often misjudged because of failure to take into account the character of the objects or surfaces viewed. A lighting installation, whether natural or artificial lighting, may be well designed and yet a person reading in the room may experience ocular discomfort because of the glossy character of the pages of the book, the size of the type, spacing of the lines, color of the page and of the print, etc., to say nothing of the discomfort caused by regular reflection from glossy walls, furniture and room trim.

The regular reflection from the surface of the familiar glass topped table is another example of a contributory cause of ocular discomfort which is not due to faulty illumination design.

To secure a good lighting result it is therefore absolutely necessary to take into account all of the factors that enter into the attainment of adequate and comfortable illumination. One of the most important of these factors is the use of matte surfaces to secure a good diffusion of light. This factor can be included in the regulations governing school furnishings and school equipment.

Instruments are now available for measuring with reasonable approximation the extent to which a surface, such as the page of a book for example, returns regular (harmful) reflection to the eye of the reader.[5] [6] It is now possible to specify reasonable limits for this factor in a school lighting code.

With a few exceptions existing state legislation relating to

[5] "A Means to Measure the Glaze of Paper." "Outline of the Theory and Construction of the Glarimeter." by L. R. Ingersoll, *Elec. World*, March 21, 1914.

[6] A. P. Trotter. See Report of British Association Committee on School Books and Eyesight; Manchester 1915; abstract in London, *Illuminating Engineer*, October 1915, p. 425.

school lighting is very general in character and directed to daylighting. Referring to New York State it is significant that whereas under the Tenement House Laws it is stipulated that "no articles shall be manufactured, altered, repaired or finished in a part of a cellar or basement of a tenement house which is more than one-half of its height below the level of the curb or ground outside of or adjoining the same," there is no state law to prevent the use of a basement similarly situated for school room purposes. In fact, in a public school building which has just come under my notice, it is planned to house the sewing class in a basement considerably below the level of the ground with consequent greatly restricted light penetration.

FACTORIES, MILLS AND OTHER WORK PLACES.

An exhaustive review of factory legislation in the United States was made five years ago under the direction of Prof. John R. Commons.[7] This review showed that the subject of lighting was rarely touched upon in the statutes and when mentioned was referred to only in the most general terms. The status of lighting legislation at the time of the review above referred to is set forth in the following quotation:[8]

> There are only eleven states that make any mention of the subject of light in their general factory or labor laws, and in not one of these are the provisions sufficiently specific to render them of practical value.

Even to-day there are few states that have on the statute books any regulations with regard to the lighting of factories, mills and work rooms other than the generic requirement that the lighting shall be adequate. In fact many of the states have not even this requirement. Where adequacy of lighting arrangements is exacted, the duty of deciding on the adequacy or the inadequacy may devolve upon the inspector of factories. As no standard of illumination is specified, there is usually room for legitimate difference of opinion as to the adequacy of the lighting.

Within the past five years there have been numerous and vital changes in legislation relating to almost all factory requirements excepting lighting. It is significant that the various legislative information bureaus throughout the country have not on file any compilation of recent state legislation relating to illumination.

[7] *American Legislative Review*, vol. I, No. 2. June 1911.

[8] "Resume of Legislative Enactments on Illumination," E. L. Elliot TRANS. I. E. S. 1911. p. 722.

However, progress has been made in this direction notably in Wisconsin and in New York State.

Wisconsin Industrial Commission.—In Wisconsin in 1913 the Industrial Commission issued "General Orders" relating to lighting. These orders consist of rules which were drafted by the commission and sent for criticism to manufacturers and manufacturers' associations and also submitted to public hearing prior to their adoption. The rules may be modified from time to time by the commission as conditions may require. The following excerpts are taken from the orders of the commission issued in 1913.[9]

Natural Light: Must be adequate during working daylight hours in buildings *hereafter constructed.*

Artificial Light: Where natural light is not sufficient in buildings *at present constructed,* artificial light must be supplied in places where hand or machine operations are performed, equivalent in amount for each 4 square feet of floor space, to not less than the light produced by 1 candlepower lamp hung 10 feet from the floor. In warehouses, storage places, vat rooms and the like when daylight is not available, artificial light must be supplied equivalent in amount for each 8 square feet of floor space, to not less than the light produced by a 1 candlepower lamp hung 10 feet from the floor. For fine lathe work, engraving, typesetting and drafting, and where the standards above specified are not sufficient to prevent injurious eye-strain, sufficient light must be provided in every case to avoid unnecessary eye-strain.

All yards, roadways, stairways, tramways and other places outside of buildings which are frequented by employees in the course of their employment, must be supplied with natural or artificial light during working hours so that every part of such place is easily discernible.

In a series of notes which supplement the General Orders, it is pointed out that in foundries and forge shops it has been found by experience that the proper amount of light is secured when the standard specified for hand or machine operations is increased 100 per cent., that is to say, is equivalent to 1 candlepower for each 2 square feet of floor space; further, that the standards specified are as low as can be safely adopted to secure results, and that many concerns have adopted standards considerably higher than these; further, that in hand and machine and similar operations covered by the General Orders where the proper standard of general illumination has been installed, it has been found unnecessary to use individual lights.

[9] *Bulletin* of the Industrial Commission of Wisconsin, vol. II, No. 1, Jan 20, 1913.

The General Orders do not specify in terms the intensity of light on the work. The only reference to the need of shading the lights occurs in a note which states that—

In many cases it is desirable to provide individual lights for each machine, bench or table. It is exceedingly important that these lights be equipped with proper reflectors which can be kept clean, and which so reflect the light that the eyes are not subjected to the glare of the light, and eye-strain is avoided.

A further note refers to the desirability of equipping lamps with reflectors, as follows:

Each lamp used for either general illumination or individual lighting should be equipped with a reflector made of white enameled steel, porcelain, glass or similar material which will not be tarnished by the gas and smoke, and which can be kept clean. The reflectors used for general illumination should be so shaped as to concentrate and distribute the light on the working plane which is usually within 7 feet of the floor. It has been found that a properly designed reflector will add about 35 per cent. to the efficiency of the lamp. These reflectors should be kept clean. It has been demonstrated that it adds from 25 to 50 per cent. to the efficiency of a reflector to keep it clean.

A further note refers to the need of whitewashing walls and keeping windows clean, as follows:

In all places of employment where there is not excessive smoke and gas, the walls and ceilings should be kept properly whitened with paint or whitewash. It has been demonstrated that in departments where the walls are whitened the natural and artificial light is increased about 20 per cent. It also adds materially to the natural light to keep the windows clean.

At the request of the commission one of the members of the committee that drafted the General Orders above recited, prepared a paper on "Shop Lighting,"[10] dated March 1, 1914, based upon his personal experience in improving the lighting equipment of a large manufacturing plant. This pamphlet is issued by the commission as a supplement to its General Orders and is intended for distribution to manufacturers to assist them in working out their lighting problems. The pamphlet contains an introduction by the commission, from which the following is quoted:

From the reports which the commission is receiving from its deputies in the field it is evident that manufacturers over the state are waking up to the value of good lighting in shops—not only its economic value, but especially its value in preventing accidents. Those manufacturers who

[10] "Shop Lighting". F. Schwarze, Electrical Engineer, Pfister and Vogel Leather Co., Milwaukee; issued March 1, 1914 by Industrial Commission of Wisconsin.

have the best lighted shops are the most positive in their recommendation of the practical value of good natural and artificial light.

Obviously a lighting specification that does not take cognizance of the actual light delivered on the work, is lacking in one of the essentials; hence the shop manager who complies with the specifications above set forth in the General Orders of the Wisconsin Industrial Commission may, even with the best intentions, fall far short of securing the result which is contemplated by the orders because the latter say nothing about the light delivered on the work. This same criticism holds for all similar factory legislation that has been adopted by the states.

Developments in the science of lighting have now reached a stage that will permit of establishing at least minimum standards of light intensity that heretofore have not been incorporated in legislation of this character. Further than that, it is now practicable to designate brightness limits with sufficient definiteness to warrant the inclusion of some specifications as to brightness in lighting requirements.

The General Orders of the Wisconsin Commission relating to the lighting of fine work, such as lathe work, engraving, typesetting and drafting, were evidently intended to correct the abuse of under-illumination, stress being laid on the requirement that there must be "sufficient light provided in every case to avoid unnecessary eye-strain."

New York State.—The recently enacted New York State law (effective October 1, 1913) goes one step further in requiring the factory owner not only to provide sufficient light for the work, but also to arrange the lighting so as to "prevent unnecessary strain on the vision or glare in the eyes of the workers." In the case of the New York State, the Industrial Commission is empowered to issue regulations with respect to lighting and to enforce these regulations.

Most of the legislation that has had to do with the lighting of factories, mills and other work places has been directed primarily to the question of *safety* and secondarily to illumination.

The two principal sections of the lighting law in New York State cover first, the lighting of passageways, moving machinery, halls and stairs leading to workrooms; and second, the lighting

of the workrooms themselves. These laws are very brief and are quoted in full as follows:

Passageways, Moving Machinery, Halls and Stairs Leading to Workrooms.—All passageways and other portions of a factory, and all moving parts of machinery which are not so guarded as to prevent accidents, where, on or about which persons work or pass or may have to work or pass in emergencies, shall be kept properly and sufficiently lighted during working hours. The halls and stairs leading to the workrooms shall be properly and adequately lighted and a proper and adequate light shall be kept burning by the owner or lessee in the public hallways near the stairs, upon the entrance floor and upon the other floors on every work day in the year from the time when the building is open for use in the morning until it is closed in the evening except at times when the influx of natural light shall make artificial light unnecessary, such lights shall be so arranged as to insure their reliable operation when through accident or other cause the regular factory lighting is extinguished.

Workrooms.—All workrooms shall be kept properly and adequately lighted during working hours. Artificial illuminants in every workroom shall be installed, arranged and used so that the light furnished will at all times be sufficient and adequate for the work carried on therein, and so as to prevent unnecessary strain on the vision or glare in the eyes of the workers. The industrial board may make rules and regulations to provide for adequate and sufficient natural and artificial lighting facilities in all factories.

The New York State Factory Investigating Commission which formulated the text of the two laws above cited, solicited and received the active co-operation of the Illuminating Engineering Society in the preparation of these laws.

Since the issuance of these laws, committees of the Illuminating Engineering Society have been active in considering the general problem of factory lighting and have completed a code for the lighting of factories, mills and other work places which was issued by the Society in 1915.[11] This code was primarily intended to serve as an aid to industrial commission and to other similar bodies in states and municipalities contemplating the enactment or revision of legislation relating to lighting of factories and workrooms. The code, which is published in separate pamphlet form, contains suggestions for legislative enactments relating to natural and artificial lighting, explanatory rules supplementing these suggestions, and explanatory notes which go into detail as to the subject matter of the code and rules.

[11] "Code of Lighting Factories, Mills and other Work Places." issued by the Illuminaing Engineering Society, TRANS. I. E. S., vol. X, Nov. 20, 1915. pp. 605-641.

The notable feature of this code is that numerical standards of minimum and desirable intensity are given for different classes of work, both for daylight and artificial light.

The artificial light requirements are as follows:

Class of work	Minimum foot-candle intensity.	Desirable foot-candle intensity
Storage, passageways and the like........	0.25	0.25– 0.5
Rough manufacturing and other operations	1.25	1.25– 2.5
Fine manufacturing and other operations	3.50	3.5 – 6.0
Special cases of fine work...............		10.0 –15.0

The above values refer to the foot-candle intensity on a horizontal plane through the work.

Daylight.—As to the daylight intensity required it is stipulated that—

At the darkest part of any work place when normal exterior daylight conditions obtain, there shall be available at least a minimum intensity equal to three times the minimum intensities given for artificial light.

British Factory Lighting Code.—Shortly after the publication of the factory lighting code of the Illuminating Engineering Society, the British Report of the Departmental Committee on Lighting on "Lighting in Factories and Workshops"[12] appeared in London. This report is limited to the consideration of the textile, engineering and clothing trades.

The British Departmental Report advocates a statutory provision giving power to the Secretary of State to make orders defining adequate and suitable illumination for factories and workshops.

To meet the specification of *suitable* lighting it is stated that the illumination should comply with the following requirements:

(*a*) A reasonable degree of constancy and uniformity of illumination over the necessary area of work.

(*b*) The placing or shading of lamps so that the light from them will not fall directly in the eyes of an operator when engaged on his work or when horizontally across a workroom.

(*c*) The placing of lights so as to avoid a casting of extraneous shadows on the work.

To meet the specification of *adequate* lighting the following numerical values for minimum foot-candle intensity of illumination (measured at the foot level) are specified:

[12] First Report of the Departmental Committee on Lighting in Factories and Workshops, London 1915. NOTE: Appendix. VIII of this report contains a resume of the light ing requirements of factories and schools in force in foreign countries.

Artificial Light:

Class of work	Minimum foot-candle intensity.
In the working areas of factories generally	0.25
In the working areas of foundries	0.4
In all parts of factories over which people are liable to pass	0.1
In open places where people are employed, dangerous parts of regular roads and approaches	0.05

The standards for minimum intensity of light specified in the British report do not refer to the intensity of illumination required on the work, which intensity, the report states, will vary greatly according to the number of the operations. The values given are apparently intended rather as minima for safety, the supposition being that the actual illumination on the work will be of very considerably higher intensity. The desirable intensities on the work are not suggested in the report. The report does not differentiate between daylight and artificial light in respect to minimum intensities required.

Direct, Indirect and Semi-indirect Lighting.—The finding of the British Departmental Committee with respect to different types of lighting and to natural vs. artificial lighting are set forth in the following conclusion of the committee:

The evidence before us from witnesses and our observations do not justify us in drawing any distinction in the present recommendations between direct, indirect or semi-indirect systems of lighting, or between systems which differ in the color composition of the light. We suggest, therefore, that the standards proposed should be adopted irrespective of the type of lighting. Similarly, the evidence does not justify us in discriminating between natural and artificial lighting, and in the recommendations submitted by us, the standards are intended to apply equally to both, that is to say, when the natural illumination falls below the limits proposed, it must be supplemented or replaced by artificial illumination.

TENEMENT HOUSES.

In a number of the states and in particular in New York the laws go into great detail in treating of the daylighting requirements of tenement houses. The height of the houses and of the different floors thereof, the exposure, size and window area of the rooms and many other requirements are specified, as for example, percentage of lot occupied, size of yards, size of outer and inner courts and light shafts, lighting of halls, elevator vestibules, basements and cellars.

New York State.—The following excerpts from the tenement house laws of New York State are of direct interest:

The height of no tenement house hereafter erected shall by more than one-half exceed the width of the widest street upon which it stands.

In every tenement house hereafter erected a total window area in each room, except water closet departments and bathrooms, shall be at least one-tenth of the superficial area of the room and the top at least of one window shall not be less than 7 feet 6 inches above the floor. * * * No such window shall be less than 1 square foot in area.

The total area of windows in a cellar room shall be at least one-eighth of the superficial area of the room.

In all tenement houses, hereafter erected, the department charged with the enforcement of this chapter may require the walls and ceilings of every room that does not open directly on the street to be kalsomined white or painted with white paint when necessary to maintain the lighting of such room and may require this to be renewed as often as may be necessary.

Walls of all yard courts, inner courts and shafts unless built of light colored brick or stone shall be thoroughly whitewashed or shall be painted a light color and shall be so maintained.

No articles shall be manufactured, altered, repaired or finished in a part of a cellar or basement of a tenement house which is more than one-half of its height below the level of the curb or ground outside of or adjoining the same.

Pennsylvania.—The Pennsylvania state laws relating to the lighting of tenement houses are much the same as those in force in New York State. Practically all of the regulations are directed to daylighting. The Chief of Housing Sanitation is empowered to order the "walls and ceilings painted, whitewashed, kalsomined or papered in white or other approved light color," when necessary to improve the lighting.

LOCOMOTIVE HEADLIGHTS.

In 1913 a committee of the American Railway Master Mechanics Association prepared a summary of laws relating to locomotive headlights.[13] A few amendments to the laws have been enacted since this compilation was published. These amendments are included in the following summary as of the year 1915:

SUMMARY OF HEADLIGHT LAWS IN THE UNITED STATES.

Electric Only:

(1) Headlight of 1,500 candlepower, measured without reflector. (Arizona.)

[13] Report of the Committee on Locomotive Headlights, American Railway Master Mechanics' Association; pp. 315-329. Circular N,1913-14; see also Railway Electrical Engineer, p. 200, Oct. 1913.

(2) Headlight of 1,500 candlepower, measured with reflector. (Missouri—effective January 1, 1914.)

(3) Headlight consuming 300 watts at the arc. (Georgia—23-inch reflector required. Mississippi—18-inch reflector required.)

(4) Headlight sufficient to distinguish an object the size of a man at 800 feet, measured with reflector. (Oregon—effective February 21, 1914.)

(5) Headlight of design approved by Railway or Public Service Commission . (Washington.)

Electric or Other Type:

(6) Headlight of 1,200 candlepower, measured without reflector. (Colorado—effective April 3, 1914. North Dakota—effective July 1, 1914.)

(7) Headlight of 1,500 candlepower, measured without reflector. (Minnesota—effective January 1, 1914; Montana and Nevada—effective January 1, 1914. North Carolina, Oklahoma, South Dakota and Texas.)

(8) Headlight of 1,500 candlepower. (Arkansas and Florida—effective October 1, 1913. Indiana.)

(9) Headlight of 2,500 candlepower, measured with reflector. (Vermont—effective April 1, 1915.)

(10) Headlight of 10,000 candlepower, measured with a reflector or sufficient to distinguish an object the size of a man at a distance of 800 feet. (South Carolina.)

(11) Headlight sufficient to enable operator to distinguish an object the size of a man lying prone on track at a distance of 1,100 feet. (Iowa—effective 1913.)

(12) Headlight sufficient to distinguish a dark object the size of a man at a distance of 800 feet while train is running not less than 30 miles an hour. (California—effective August 11, 1913.)

(13) Headlight sufficient to distinguish an object the size of a man at a distance of 800 feet. (Illinois—passenger train locomotives only; effective July 1, 1913. Kansas and Wisconsin.)

(14) Headlight sufficient to distinguish an object the size of a man at 600 feet by a person of normal vision. (Nebraska—effective Jan. 1, 1914.)

(15) Headlight sufficient to distinguish an object the size of a man at a distance of 450 feet. (Illinois—freight train locotomives only; effective July 1, 1913.)

(16) Headlight sufficient to distinguish whistling posts, land marks and other warning signs at a distance of 350 feet. (Michigan—effective July 1, 1914. Ohio.)

(17) Headlight sufficient to distinguish an object the size of a man at a distance of 250 feet. (Illinois—switching transfer or suburban passenger service only; effective July 1, 1913.)

(18) Headlight of 50 candlepower, measured without reflector. (Minnesota—switching locomotives only; effective January 1, 1914.)

Note.—An amendment to the headlight law in Nevada, passed in 1915, stipulates that any headlight "which will pick up and dis-

tinguish an object the size of a man dressed in dark clothing on a dark and clear night at 1,000 feet," shall be deemed equivalent to a 1,500 candlepower headlight measured without reflector.

The wide difference in the provisions of these laws makes it impossible for railways running through several states to make use of headlights that comply with the law of each state.

This incongruous situation with respect to headlight legislation in the different states led to the introduction of a bill in Congress in 1914 looking to the use of a standard type of locomotive headlight in all the states. The standard proposed was a headlight "1,500 candlepower without reflector." This bill was defeated. In the discussion of the bill it was pointed out that the headlights of intense candlepower tended to blind the eyes of the engineer of a locomotive going in the opposite direction, also preventing the easy reading of colored signals. Tests have also shown that under certain conditions a powerful head-lamp may distort colors of signals owing to reflection from the glass roundels.

The committee of the American Master Mechanics Association which made a special study of the situation including an extended series of tests, reported in favor of a very much smaller unit with reflector, giving an "apparent beam candlepower not greater than 3,000 referred to the center of the reference plane of from 500 feet to 1,000 feet ahead of the locomotive."

It is evident laws requiring 1,500 unreflected candlepower are misleading and really mean nothing where track illumination is concerned. It has been suggested that a better specification for a head-lamp would be one which should have an average beam candlepower of not less than 100,000 measured at a distance of not less than 500 feet over a 2-degree spread.[14] This is a concrete figure and one that can be met by head-lamp manufacturers.

Automobile Headlights.—The regulations governing headlights vary greatly in different municipalities. For example, in Chicago (ordinances of 1913), the regulations state that—

> It shall be unlawful to use any headlight the rays from which shall be intensified by any parabolic or condensing reflector, unless such headlight shall be properly shaded, so as not to blind or dazzle other users of the highway or make it difficult or unsafe for them to ride, drive or walk thereon.

[14] "Fundamental Principles of Head-lamp Illumination," by L. C. Porter and K. W. Mackall, Electrical World, July 19. 1913.

In the State of New Jersey the new laws (Chapter 129, P. L., 1915) specify that on motor vehicles—

No light shall be used the direct rays from which shall be projected at a greater height than a parallel of 4½ feet from the road; or if projected at a greater height all dazzle or glare must be eliminated.

In New York recent regulations proposed are as follows:

The headlights of all automobiles shall give sufficient light to reveal any person, vehicle or substantial object on the road straight ahead of such automobile at a distance of at least 150 feet. The headlight shall be so arranged that no portion of the reflected beam of light when measured 75 feet or more ahead of the car shall be over 42 inches above the level surface on which the car stands. Such headlights shall also give sufficient side illumination to indicate any person, vehicle or substantial object 10 feet to the side of said automobile at a point 10 feet ahead of the lamp.

STREET LIGHTING.

The problem of street lighting is unlike that of interior lighting and presents greater difficulties than the latter from a legislative standpoint. The tendency of the times is to invest in Public Utility Commissions the power to pass upon questions of street lighting and to issue regulations with reference thereto. As the demands of street lighting vary greatly in different cities and in different portions of the same city, and as the expenditure for the lighting varies greatly with the financial resources of the community, regulations as to details should come directly under the municipalities concerned.

Specifications have been drawn by qualified engineers and representatives of municipalities and public service lighting companies, which serve as a basis for contractual arrangements between the municipalities and the lighting companies.

In street lighting where the lamps are usually mounted on high posts, the need of shading the lamps is not nearly so important as in the average case of indoor lighting, where the lamps are often within view for a protracted period of time. However, there is need of regulation with regard to the standing of street lamps especially in residential districts, and in all cases where the lamps are mounted low.

The size of the lighting units and the best spacing and mounting heights to meet specified conditions in street lighting are still the subject of considerable controversy, but the time seems ripe

for legislative enactments relating to some of the fundamentals that have been agreed upon in respect to illumination factors.

DAYLIGHTING AND CITY PLANNING.

The importance of this phase of lighting legislation was alluded to in a paper presented at the Cleveland Convention of the Society in 1914.[15]

In that paper there is an analysis of the factors governing daylight admission to buildings, such as the size, shape, depth and position of the window openings, the character of glassware in the windows, the height of opposite buildings, the diffusion of light from adjacent buildings and the street surface, etc. There is also a discussion of building conditions and regulations, supplemented by a table of buildings height limits in American and European cities. Most of the laws on the statute books having to do with the lighting of buildings in the several states, relate to natural lighting, and are concerned with the hygienic aspect of lighting primarily, and the illumination aspect secondarily. As the statutes prescribe no standards the legislation is apt to be meaningless, especially in cities where very high buildings are erected on opposite sides of narrow streets.

Fortunately in some of the cities municipal legislation has recently been directed to planning for good daylight and ample sunlight in buildings, especially in tenement houses.

It is a notable fact that in European cities the building height limits are only one half to one third those of American cities. To provide for good daylighting the width of the street must be considered in connection with the height of abutting buildings. In European cities the height of the buildings is usually less than the width of the street; whereas in American cities the height of the building is often two to three times the width of the street and in the case of "sky scraper" localities, as in New York City, five or more times the width of the street.

The laxity of city ordinances with respect to building height limits, etc., renders futile all attempts at city planning in relation to proper admission of daylight and sunlight in buildings. Even where regulations exist as to building heights there is no pro-

[15] "Planning for Daylight and Sunlight in Buildings," by L. B. Marks and J. E. Woodwell, TRANS. I. E. S., vol. IX, 1914, p. 643.

See also Report of the Heights of Buildings Commission, New York City, Dec. 23, 1913.

vision for the orientation of buildings, such as school buildings, hospitals, homes, etc., to secure the best conditions of lighting from the double standpoint of hygiene and illumination.

In city planning the municipality in considering the well-being of its people should start with the premise that—

> All buildings in which human beings dwell or work should have all of their exterior walls exposed to the direct sunlight at some time during the day throughout the year, and that the surface of streets, alleys, areas, courtyards, and other spaces in and around buildings should also be exposed as much as possible to the action of direct sunlight.[16]

In addition to the considerations above cited, an important factor in planning for adequate daylight, especially in sections of cities where buildings are congested, is the reflective values of the exterior walls of buildings. It has been shown that as between dark colored and light colored building fronts in portions of the city having high buildings, the daylight received at the ground floor opposite light colored buildings is almost double that received in a similar location opposite dark colored buildings.

Easements of Light, Air and Access.—The desirability of enacting legislation to limit the height of buildings in cities has been referred to. Under the law a property owner is entitled to three easements, namely, light, air and access. If a viaduct or an elevated railway is built on the street in front of his premises, he is entitled to recover damages for loss of daylight caused by the obstruction due to the erection of such a structure. The legal aspect of a case of this kind presents the following anomalous situation: the property owner may recover from a railway corporation for even a trivial loss of light, but he cannot recover from the city or from any individual or corporation for a great loss of light resulting in ruinous darkening of his premises by virtue of the erection of a block of "sky-scraper" buildings on the opposite side of the street.

FEDERAL, STATE AND MUNICIPAL LEGISLATION.

As a general principle, "home rule" in matters relating to lighting, would seem to be the most workable and therefore the most effective means to secure and enforce good lighting legislation.

There are, however, several fields of lighting, the regulation of which would seem to belong more properly to the state, and

[16] "Orientation of Buildings or Planning for Sunlight," by Wm. Atkinson, p. VIII.

still others to the federal government; for example, regulations for the lighting of schoolhouses may well be taken over by the state to secure the proper co-ordination of natural and artificial lighting facilities in all schools and to properly safeguard the eyesight of children. The state statutes would preferably cover the general requirements of all schools, leaving the municipalities to specify the detailed requirements to meet local conditions. The same situation with respect to state and municipal lighting legislation holds for factories, mills and other work places.

In the matter of street lighting, the state statutes would cover state highways and state parks; the municipalities would work out their own street lighting specifications until such time as standard requirements may be agreed upon for the lighting of cities of the first, second and third classes respectively.

In any event it does not seem desirable to have on the statute books of the state any legislation relating to details of lighting that may require frequent amendment owing to the progress of the science and art of lighting. This situation is met by the plan carried out in several of the states to vest in a commission, industrial board or other board, the right to make orders and issue regulations for the lighting of buildings and streets. Such orders have all the force of statutes and may be revised from time to time to suit conditions without amending the broader statutes of the state to which they are subsidiary.

Another class of legislation to which references has been made, would seem to come properly directly under the federal government. Such legislation would include all lighting the regulation of which would come within the province of more than one state, as for example, requirements of locomotive headlights on interstate railways. The present anomalous situation of headlight legislation in the various states has already been commented upon. The solution of the difficulty lies in the passage of a federal law on the subject.

A classification of lighting legislation in accordance with the three main divisions above proposed would include the following:

Federal Legislation:

Locomotive headlights on interstate railways.

Regulations as to lights on land and water, that affect visibility of interstate railway signals.

Railway postal cars.

Lighthouse and harbor light service and regulations to prevent interference by other lights.

Lighting of federal buildings and grounds.

State Legislation:

Schoolhouses: broad specifications to cover general requirements for all schools.

Factories, mills, etc.: broad specifications to cover general requirements.

State railways and state parks.

Municipal Legislation:

Schoolhouses: detailed specifications to meet local conditions.

Factories, mills, etc.: detailed specifications to meet local conditions.

Courthouses, armories, railway terminals, theatres, libraries, tenements, hospitals, hotels, museums, auditoriums, public baths, etc.

Streets, parks, etc.

City planning: limitation of heights of buildings, and other daylighting requirements.

STRIKING FACTS IN LIGHTING LEGISLATION.

The foregoing paper hardly admits of summarization, but a review thereof leads to the conclusion that in matters of lighting legislation the laws of the statute books err rather on the side of omission than of commission. The consideration of the subject discloses the following striking facts:

1. The statutes relating to lighting are as a rule crude and fragmentary, and often meaningless.

2. Notable absence of legislation directed to safeguarding the eyesight of the public.

3. Notable absence of lighting legislation directed to prevention of accidents.

4. Lack of co-ordination and standardization of legislation in the different states.

5. No systematization of federal, state and municipal legislation.

6. Legislation relating to buildings directed mainly to daylighting.

7. Absence of definite specifications relating to artificial lighting.

8. In street lighting legislation, the criterion is often the power supplied and rarely the distribution of illumination on the street.

9. Absence of definite and complete regulations for the proper lighting of school buildings and other public and semi-public buildings and of factories and work rooms.

10. In most states there is no law to prevent hanging brilliant unshaded lamps directly in front of the eyes of school children or workmen.

11. In New York State it is unlawful to locate a liquor saloon within 200 feet of a school; but the statutes do not provide against the erection of buildings 200 feet high opposite the school even though the daylighting of the schoolrooms be thereby ruined.

12. In some states it is unlawful to locate a workroom in the basement of a tenement, but the statutes do not provide against housing a class of children below the ground level in the basement of a public school building.

13. Workmen's compensation laws compensate for accident and occupational diseases but not for eye diseases caused by bad lighting.

14. Absence of regulations relating to mixture of daylight and artificial light in schools and workrooms.

15. Absence of regulations relating to the color of artificial lights in public buildings.

16. Absence of regulations to prevent exposure of the eyes to dangerous radiation of ultra-violet light, etc.

17. No general safety rule for independent systems of lighting in factories, public buildings, tunnels, etc.

18. Oversight of the fact that the surroundings (color and finish of walls, furnishings, etc.) are a vital factor in prescribing illumination requirements.

19. Absence of laws in relation to lighting of moving pictures (inadequate intensity, excessive flicker, etc.).

20. Incongruity of locomotive headlight legislation for interstate railways. The requirements differ in almost every state and it is not practicable to comply therewith in interstate transportation.

21. Absence of laws to prevent the placing and operation of lights where they interfere with the visibility of railway signals, thus endangering the lives of passengers on trains.

22. Absence of effective protective legislation against the blinding light of automobile headlights.

23. In general, absence of requirements as to minimum illumination intensity and maximum permissible brightness.

24. Absence of legislation on city planning with reference to orientation of buildings and streets, height of buildings, color of building fronts, etc., to secure the best conditions of daylighting and sunlight penetration.

25. Most legislation on the statute books, relating to daylighting of buildings, is inadequate in that the ratio of window area to floor area is the only basis specified to ensure adequate daylighting.

REFERENCE BUREAU FOR INFORMATION ON ILLUMINATION.

The Illuminating Engineering Society was organized ten years ago to advance the theory and practise of illuminating engineering and to disseminate knowledge relating thereto. The Society has no affiliation with any commercial organization and is admirably suited to act as a clearing house for authoritative information relating to the subject of natural and artificial lighting. The Society welcomes cooperation with legislative bodies and others who are interested in the enactment of statutes, ordinances, rules and regulations for lighting.

DISCUSSION.

PROF. C. E. CLEWELL: There is one thing I should like to add to the discussion on Mr. Marks' notable paper. It relates to the enforcement of legislation. There has in the immediate past been more of an incentive to improve lighting conditions, particularly in the factory lighting field, than the mere adherence to certain laws.

In 1910, I think it was Mr. Roosevelt, then one of the editors of the *Outlook,* who made some inspections of shops in and around New York City. At that time I was associated with the Westinghouse Electric and Manufacturing Company, and had the privilege of transmitting to Mr. Roosevelt the results of some of our studies at East Pittsburgh in connection with industrial lighting. Following this, an arrangement was made with the *Outlook* for the publication of an article on the subject "Environment in American Shop Life" in which I outlined three incentives for the managers of establishments or industrial concerns to render the environment more suitable for the work of the employee. One of these incentives has resulted, at least to a certain extent, from the trades unions whose various agitations—some of which may have been wrong—have aroused public opinion to the needs of the worker. A second incentive comes from the direct or indirect economic effect of better conditions on the output of manufacturing plants. A third comes, of course, from the necessity of adhering to certain legislation where it may exist.

Now I have always contended, and I say this from the viewpoint of practical experience, that is is usually much easier to get legislative enactments sympathetically adhered to, if it can be shown to the management what economical advantage will result by following out the enactments. Hence, when we come to any legislation that relates, for example, to factory lighting, it will be found, I am sure, that it is exceedingly valuable in any attempt to apply this legislation, for instance through Pennsylvania, to transmit some information to managers regarding the economic returns from good lighting.

In the new code of the Illuminating Engineering Society certain sections have been devoted to these economical returns, but this does not mean that the human side of the question should be

eliminated. Good light should be provided for humane reasons, if for no other, but a manager who can see that by being humane he can gain at the same time a return for himself in financial ways, has a double reason for following out the suggestions of a commission such as we have in this state.

Mr. Lewis Bryant: In my twelve years' experience as the Commissioner of Labor of the State of New Jersey I have seen the growth of factory legislation from its infancy. Ten or twelve years ago the factory departments of New Jersey and practically all the other states were a sort of roosting place for broken down politicians. I remember when I became a Commissioner some of the factory inspectors for the different districts of the state were editors of small newspapers or men who had no particular qualifications for the position; in fact they were not supposed to put very much intelligence into their work.

Now I think the American conscience has commenced to awaken to the fact that it has a sacred obligation in looking after the health and the comfort of the hundreds of thousands of men in the various industries. We know how the safety-first movement has grown. Steps have been taken to prevent physical injury of workmen by the safeguarding of machinery, covering vats, etc.; yet these efforts which of course are all perfectly right in their place constitute only a very limited application of safety-first principles.

I have often said the American people seem to need something spectacular to attract their attention. In 1910 there occurred in High Street, Newark, the first of the series of large fires in the State of New Jersey. Some twenty-five girls were burned under the most harrowing circumstances. Their bodies were washed around in the gutter by the water from the firemen's hose. The next day in the City of Newark there were a hundred thousand people to see the remains of this fire. It was almost as much as a factory inspector's life was worth to walk on the street. The following year, according to statistics in the Department of Labor, the three items of slipping ladders, belts and elevators caused a loss of within one or two as many people as this fire and there was not one word of protest raised in the entire state. I have often said that a person who has been burned will generally get a head-line in the paper; one who has fallen down an elevator

shaft will get only two or three lines in some part of the paper and one who unfortunately contracts and succumbs to an occupational disease, such as lead poisoning, will get an obituary, if there is money enough to pay for it.

I was very much pleased with the remarks Mr. Marks made about the employees compensation schedule not including injury to the eyes from bad light. Why shouldn't a workman be expected to have proper light, the same as proper air to breathe? If he is forced to work in an improperly lighted workroom or where the light is shining in his face, as I have seen in factories, why isn't that just as much an injury, by reason of his occupation, as having his finger cut off, for instance; it may be very much more serious to him, it may be a very much greater handicap in his occupation during future life. The safety-first propaganda should be taken in a very broad way. I think we should even safeguard operatives' comfort. Besides those suffering from lead poisoning and other occupational diseases there are in this country, it is estimated by statistics, about three million workers suffering because they are only negatively well; they go to work every day but they are not in a position to give the full 100 per cent. value which they should give, and which they have a right to give to their employer. How much of that is occasioned by improperly lighted workrooms? How many have contracted headaches due to improperly lighted workrooms, or to lights shining in their eyes? The conditions of a workroom should be such as to enable a worker who gets the proper amount of rest to come back to his task the next day prepared to do an honest day's work. Otherwise the worker becomes a burden on the community. No employer has a right to expect a man to give a portion of his life or his death, or his eyesight, for money compensation. The employer doesn't pay for that. What surprises me is the absolute lack of intelligence on the part of so many good manufacturers in the use of light. They do not know anything about it. I have often explained to the factory inspectors that the mere use of a piece of paper to screen lights from the eyes would often constitute splendid work. I believe that this matter should be taken up in the form of scientific standards and that these standards should be expressed in language which the ordinary layman will understand.

ILLUMINATION EFFICIENCIES AS DETERMINED IN AN EXPERIMENTAL ROOM.*

BY WARD HARRISON AND EARL A. ANDERSON.

Synopsis: The authors describe a series of illumination tests performed in a portable room designed for this purpose. The room dimensions and the arrangement of the outlets were varied to approximate the diverse conditions met in practise. Wall, ceiling and floor combinations of white, black and intermediate colors were tested with units of three general types of light distribution. Using the data in this paper as a basis, additional tests with other reflectors are planned to obtain a more complete comparison of the efficiencies of the various types of lighting equipment now in common use.

INTRODUCTION.

Many tests have been made of different types of lighting equipment under the same room conditions. Experimental comparisons between the utilization efficiencies of lighting installations with varied shades of walls, ceiling, and floor have also been reported.[1] However, the unavoidable limitations existing in any permanent room have tended to narrow the range of investigation in each case. The series of tests which form the subject of this paper were performed in a portable test room whose dimensions, outlets and colors could be readily adapted to represent any of the general conditions found in practise.

The data to be presented include complete sets of tests on units supplying three general types of light distribution, *i. e.*, totally direct, totally indirect, and a distribution which divides the light equally between the upper and lower hemispheres with the maximum at the horizontal. The bare lamp curve was taken to be the best example of this distribution. The units were suspended in five representative room arrangements and tested with three shades of walls, each in turn combined with four ceiling shades ranging from white to black. In addition, certain combinations were tested with white, and black, as well as with

* A paper presented at the ninth annual convention of the Illuminating Engineering Society, Washington, D. C., September 20-23, 1915.

[1] Lansingh and Rolph, TRANS. I. E. S., 1908.
Sharp and Millar, TRANS. I. E. S., 1910.

the wood floor so that the total number of distinct set-ups was nearly 200. Plans now made contemplate using the data obtained for the three types of light distribution in abbreviating the number of tests required to form a complete comparison of representative specimens of practically all types of reflecting equipment. The purpose of this paper is to set forth the results which have been secured up to the present for the value they may possess for the members of the Society, without any effort to make an analysis tending toward the expression of the results by means of formulae, or the deduction of definite conclusions. A brief description of the experimental room is included, and for those to whom it is of interest, a detailed summary of the test methods followed is added in the appendix.

EXPERIMENTAL TEST ROOM.

The experimental test room, which was designed and built after the principle of stage settings, was capable of extension to maximum dimensions of 13 ft. 6 in. x 27 ft. (4.11 x 8.22 m.) long. The ceiling framework was suspended from block and tackle combinations so as to be readily raised or lowered to any desired point within a maximum of 14 ft. (4.26 m.).

A careful consideration of the various surface materials available led to the selection of a composition board, known commercially as Beaver Board, for the walls. This material was made up into panels about 40 in. (1.21 m.) square. Hooks in the wall frame work pass through brass grommets placed in the corners of each panel and secure it in place. The composition board has a good smooth mat surface on both sides; therefore an economy in material, and in the time devoted to making changes, was effected by using the opposite sides for different colors. The side wall panels were made up uniformly so as to be reversible and entirely interchangeable. Hence, the third or intermediate wall shade which was necessary for a complete series of tests, was obtained by alternating the white and black panels as illustrated in the photograph of Fig. 3. Since only one-half the panels were handled for each wall change, this plan obviously shortened the time required and in addition made possible a further economy in material.

Exactly equal areas of white and black exist when half the wall

panels are reversed, and since the arrangement of the alternate squares is symmetrical with respect to each system of light outlets, the average illumination is unaffected, although the variations in intensity are slightly greater than where a wall of uniform color is used. The squares are small enough with respect to the distance across the room so that so far as multiple reflection between walls is concerned there is no tendency for all light reflected from a white square to fall on the opposite black one. The reflection coefficient of the mixed wall can therefore be taken as the average of the coefficients for the white and the black walls.

The large number of squares required to obtain a symmetrical ceiling arrangement with respect to all of the outlets made it impractical to secure a ceiling of medium reflecting power by following a similar method. A second set of panels was therefore necessary and instead of utilizing one side only, both sides were painted, so that four ceiling shades, white, black, light gray and dark gray were made available. Each ceiling could of course be combined with black, white or medium walls and twelve color combinations of walls and ceiling were thus provided.

The floor of the laboratory in which the experimental room was set up is of well worn oiled oak. A white or black test floor was obtained by covering the wood floor with stout paper.

The wall and ceiling panels were covered with paints selected for their good diffusion, and proper reflection coefficients. Measurements on specimens of the wall and ceiling panels and the floor coverings of the test room form the basis of the average values for coefficients of reflection given in Table I.

TABLE I.—COEFFICIENTS OF REFLECTION.

Ceiling	Per cent.	Walls	Per cent.	Floor	Per cent.
White	81.0	White	81.0	White	84.0
Light gray	64.0	Medinm	42.5	Natural wood	14.0
Dark gray	33.0	Black	4.3	Black	7.6
Black	4.3				

The measurements were made by the comparison method described in a previous paper before this society.[2] Briefly, it consists of comparative surface brightness measurements made on the material to be tested and a sheet of standard blotting paper in the same position under a constant well diffused light. The

[2] Edwards and Harrison, TRANS. I. E. S., 1914.

value of the coefficient of reflection for the blotting paper had been previously determined by the Nutting[3] reflectometer method.

The thirty outlets provided in the ceiling are arranged as shown in Fig. 1. These are so spaced that symmetrical arrangements of 1, 4 or 9 outlets may be had in each square comprising one-half the total area of the room. In the full rectangle symmetrical arrangements of 2, 8 or 18 outlets may be had, and in addition a single row of 4 or 6 units is provided along the center line of the room. Changes in the hanging height of the units are made by adjustments of the sections of conduits which carry the sockets. A set screw in the crowsfoot which grips the pipe at a point just below ceiling serves to secure the unit at any desired point.

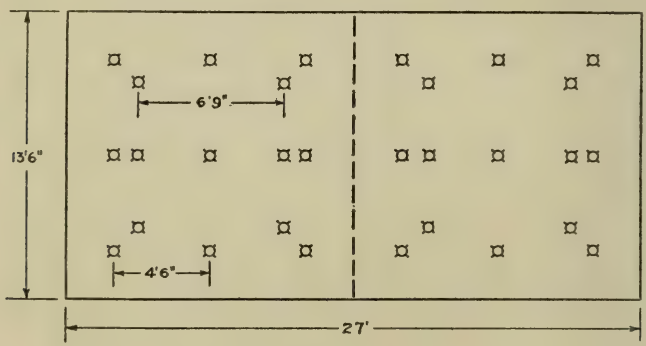


Fig. 1.

From the large number of room dimensions and lamp positions possible in the experimental area, five combinations were chosen which were thought to cover the more common conditions found in practise. Two were selected to represent what might be termed extreme cases and the relative dimensions of the other room were between these two. The five types may be described briefly as follows:

The first represents a square high ceiled room, the ceiling height was in fact slightly greater than the other dimensions. In accordance with the general practise this room was lighted from a single outlet centrally located. The other extreme case is that of a large room having a comparatively low ceiling and lighted by a

[3] Nutting, P. G., Trans. I. E. S., 1912.

Fig. 2.

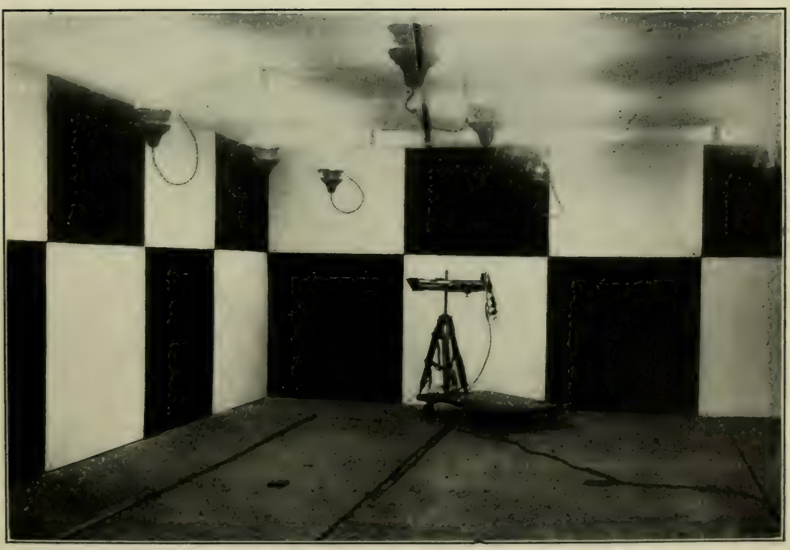


Fig. 3.

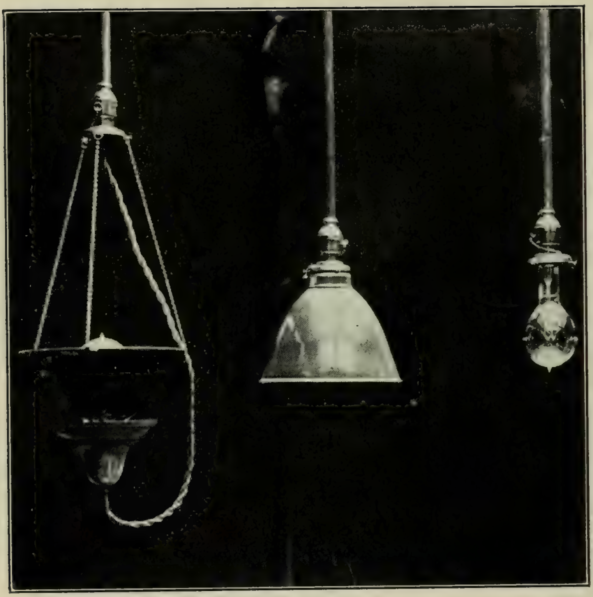


Fig. 4.

Fig. 5.

distributed system of many outlets. This room is representative of large general offices, department stores, or modern factories.

The third representative case is that of a room of approximately equal floor dimensions and a moderate ceiling height. A square room with four outlets was used to fulfil this condition. It is typical of a small office or a single enclosed bay in a factory. The room also reproduces fairly well the proportions of many halls, school rooms, small shops and other locations.

The fourth room is rectangular, has a good height of ceiling and is lighted by means of two rows of outlets of four units each. This case is typical of standard city stores which in the aggregate are of large importance.

The fifth case is that of a rectangular room with two units, symmetrically placed. This system of lighting is not representative of the best practise in office or factory illumination but is often applicable to ball rooms, hotel lobbies, and the like.

In selecting the test room combinations no effort was made to cover the conditions which are presented in residence lighting, because the lumens-per-watt efficiency is not the important factor in this class of lighting. Table II contains the dimensions and other essential data for the test rooms which represent directly or in proportion[4] the five general types chosen.

TABLE II.—EXPERIMENTAL TEST ROOM COMBINATIONS.

Room	Width Feet	Length Feet	Ceiling Feet	Test plane Feet	No. units	Height of units above plane Feet	Spacing ratio
A	13.5	13.5	14	3	1	8 50	1.59
B	13.5	13.5	14	5	4	5.50	1.04
C	13.5	27.0	9	3	8	4.33	1.56
D	13.5	27.0	6	3	18	2.17	2.08
E	13.5	27.0	12	3	2	6.50	2.08

Appearance, diffusion of light, and the other qualities which are so important in an actual installation, were disregarded in making the selection of the lighting units for these basic tests. Attention was given only to the form of light distribution.

[4] Exceptions exist in rooms B and D where the ceiling height in the experimental room is not in direct proportion to the other dimensions. To obtain a 12 ft. (3.65 m.) ceiling in room B the test plane was raised from 3 ft. to 5 ft. (0.91 to 1.52 m.). In Room D the test plane was increased from 1 ft. to 3 ft. (0.30 to 0.91 m.) for greater convenience in making tests. However, since the distance from the test plane to the ceiling was kept in direct proportion, the lower wall and floor reflection were the only factors affected. Computations indicated that the maximum variation introduced was less than 2 per cent.

Lamps of 100-watts were used in all room arrangements except D where to bring the actual size of the units into conformity with the proportions of the room, 40-watt units were chosen.

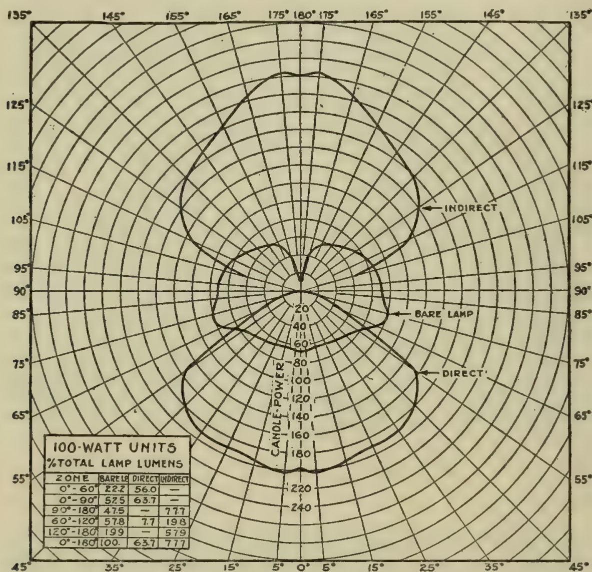


Fig. 6.

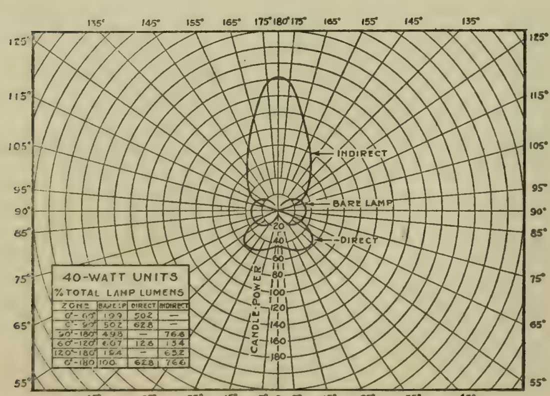


Fig. 7.

Photographs of the three types of units are shown in Figs. 4 and 5. Porcelain enameled steel reflectors exemplified the gen-

eral type of downward light distribution. Silvered glass reflectors supported in skeleton fixtures were used for the totally indirect form of lighting. The bare lamps furnished the third type of distribution. Curves for the three 100-watt units are plotted on the same sheet in Fig. 6 and the light distributions of the 40-watt units are similarly illustrated in Fig. 7. Average efficiencies for all units are given in Table III.

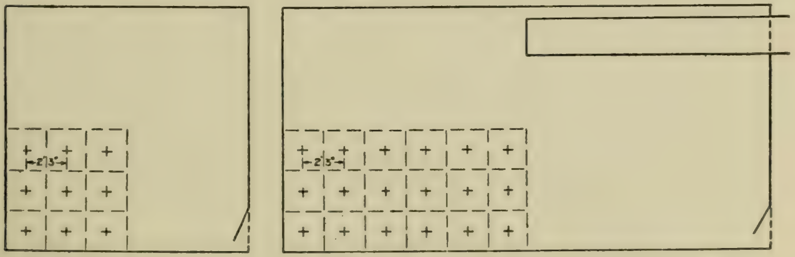
Although the distribution curves of the 40-watt units are not exactly similar to those of the 100-watt sizes, the differences are not sufficient to have a material effect upon the results.

TABLE III.—EFFICIENCIES OF REFLECTORS PER CENT. TOTAL BARE LAMP LUMENS.

	40-watt Per cent.	100-watt Per cent.
Bare lamps	100.0	100.0
Direct (porcelain enameled steel)	62.8	63.7
Indirect (silvered glass)	76.6	77.7

TEST PROCEDURE.

A detailed description of some of the test methods followed is given in the appendix; only a general outline will therefore be included here.



Figs. 8 and 9.

Because of the large number of tests to be performed, every effort was bent toward reduction in the amount of time and labor required for each test where the economies would not impair the accuracy of the test results. Since all arrangements of units tested were entirely symmetrical, illumination readings were confined to one quarter of the room. The quarter was divided up into squares 2.25 ft. x 2.25 ft. (0.68 m.) as indicated in Figs. 8 and 9, and test stations were located at the center of each square. Thus nine stations were required for the small rooms and eighteen for the large rectangular rooms.

Preliminary tests showed that the results from the quarter of the room were extremely close to the general average. The only variations noted were in the case of steel reflectors and were due to inequalities in the reflecting qualities of the individual samples. To offset this variation as far as possible, the reflectors which were near or over the test stations were placed on the same outlet in each comparative test.

All test observations were made with a standard Weber portable photometer equipped with a flat diffusing plate. The important element of time ordinarily required for moving the portable photometer from place to place, and locating the test plate accurately over the station, was minimized by the use of the photometer carriage illustrated in the photograph of Fig. 3. The photometer tripod is firmly attached to a platform mounted on rubber bound casters and the test plate is located directly above a pointer fastened to the platform. When the photometer has been adjusted at the proper height and leveled, the spot reader, who sits on the platform, readily wheels himself from station to station and quickly and accurately locates the photometer test plate over the station by means of the pointer.

To facilitate the work, two shifts of three men each were assigned to the test performance. Not only was the total time required diminished to one-half by both day and night working periods but the test results of each shift could be conveniently verified by independent checks made by the individuals of the other shift at the next working period.

The appendix describes in detail the methods pursued in order to obtain the highest degree of accuracy possible throughout the tests. The variations in individual test results which persist are very largely eliminated when values are read from the curves of test results. All test results are low, however, by as much as 12 per cent. on account of the error introduced by the imperfect diffusion of the photometer test plate. This error varies somewhat according to the nature of the installation tested, as shown by the curves previously published in the TRANSACTIONS.[5] The error is greater for units supplying distributions with large horizontal components and it will be less for indirect

[5] Edwards and Harrison, Accuracy of Photometry; vol. 8, (1913).

systems of illumination. The characteristics of the plate used agree closely with the published curves. For absolute illumination values, therefore, the proper correction as determined from these curves must be added to all test results given in this paper. When so corrected the results should be within the limits of accuracy required in any practical use to which they may be put.

TEST RESULTS.

The utilization efficiencies for the three types of light distribution tested in the five representative room arrangements are plotted for each of the three wall shades with ceiling reflection coefficients as abscissae in Figs. 10 to 14.

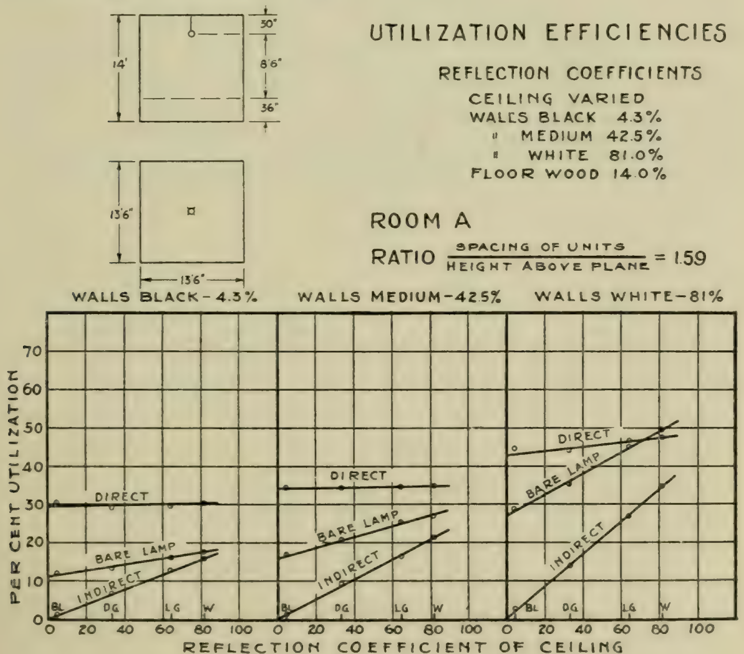


Fig. 10.

The test results for the two extremes in room construction, *i. e.*, the high small room where the wall effect is greatest (designated as A) and the large low ceilinged type where the walls have less influence (designated as D) are repeated in the curves of Figs. 15 and 16, except that here wall reflection coefficients are made abscissae and curves are drawn for each of the test ceilings used.

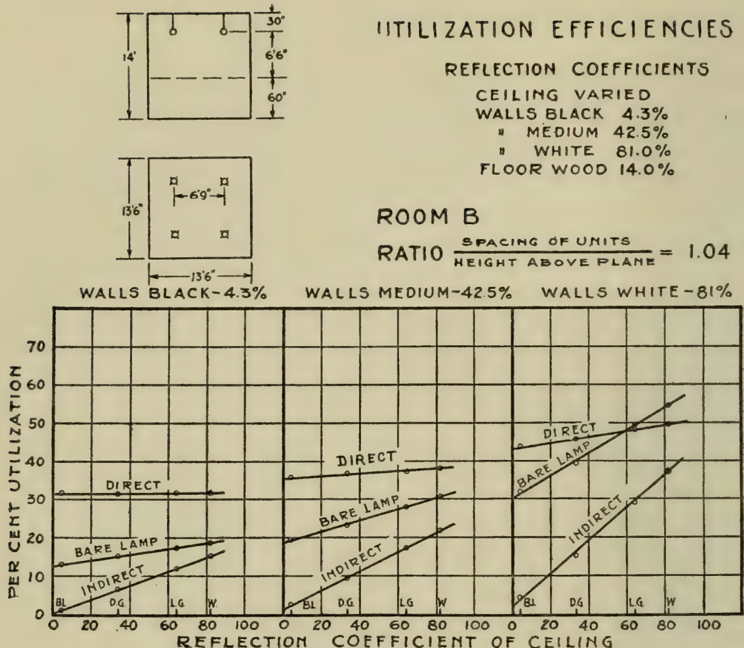

UTILIZATION EFFICIENCIES
REFLECTION COEFFICIENTS
CEILING VARIED
WALLS BLACK 4.3%
" MEDIUM 42.5%
" WHITE 81.0%
FLOOR WOOD 14.0%
ROOM B
RATIO $\frac{\text{SPACING OF UNITS}}{\text{HEIGHT ABOVE PLANE}}$ = 1.04
30"
6'6"
60"
14'
6'9"
13'6"
13'6"
WALLS BLACK-4.3%
WALLS MEDIUM-42.5%
WALLS WHITE-81%
DIRECT
BARE LAMP
INDIRECT
BL
D.G.
LG
W.
PER CENT UTILIZATION
REFLECTION COEFFICIENT OF CEILING

Fig. 11.

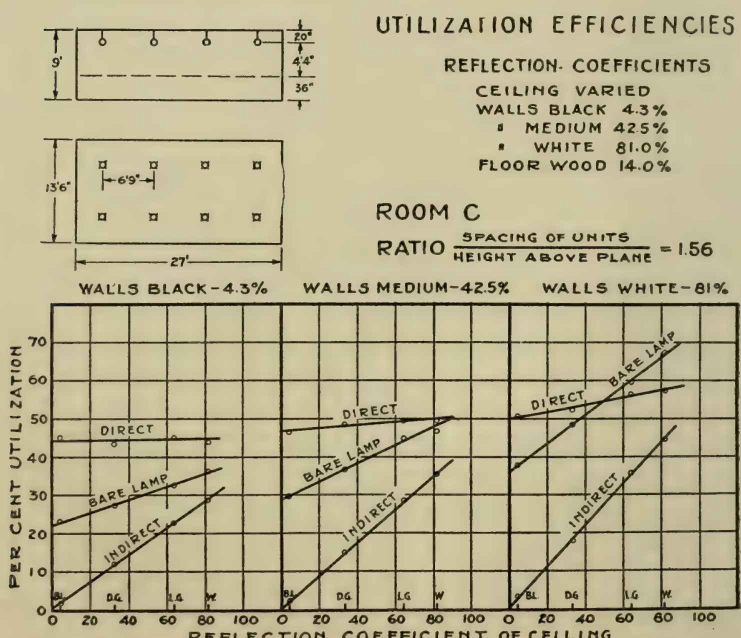

UTILIZATION EFFICIENCIES
REFLECTION COEFFICIENTS
CEILING VARIED
WALLS BLACK 4.3%
" MEDIUM 42.5%
" WHITE 81.0%
FLOOR WOOD 14.0%
ROOM C
RATIO $\frac{\text{SPACING OF UNITS}}{\text{HEIGHT ABOVE PLANE}}$ = 1.56
20"
4'4"
36"
9'
6'9"
13'6"
27'
WALLS BLACK-4.3%
WALLS MEDIUM-42.5%
WALLS WHITE-81%
DIRECT
BARE LAMP
INDIRECT
BL
D.G.
LG
W.
PER CENT UTILIZATION
REFLECTION COEFFICIENT OF CEILING

Fig. 12.

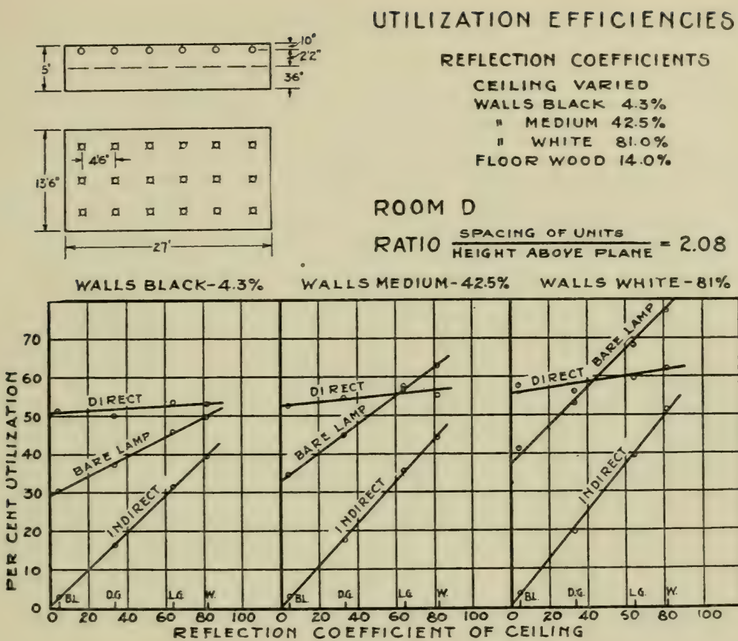

UTILIZATION EFFICIENCIES
REFLECTION COEFFICIENTS
CEILING VARIED
WALLS BLACK 4.3%
" MEDIUM 42.5%
" WHITE 81.0%
FLOOR WOOD 14.0%
ROOM D
RATIO SPACING OF UNITS / HEIGHT ABOVE PLANE = 2.08
10"
2'2"
36"
5'
4'6"
13'6"
27'
WALLS BLACK-4.3%
WALLS MEDIUM-42.5%
WALLS WHITE-81%
PER CENT UTILIZATION
DIRECT
BARE LAMP
INDIRECT
BL.
D.G.
L.G.
W.
REFLECTION COEFFICIENT OF CEILING

Fig. 13.

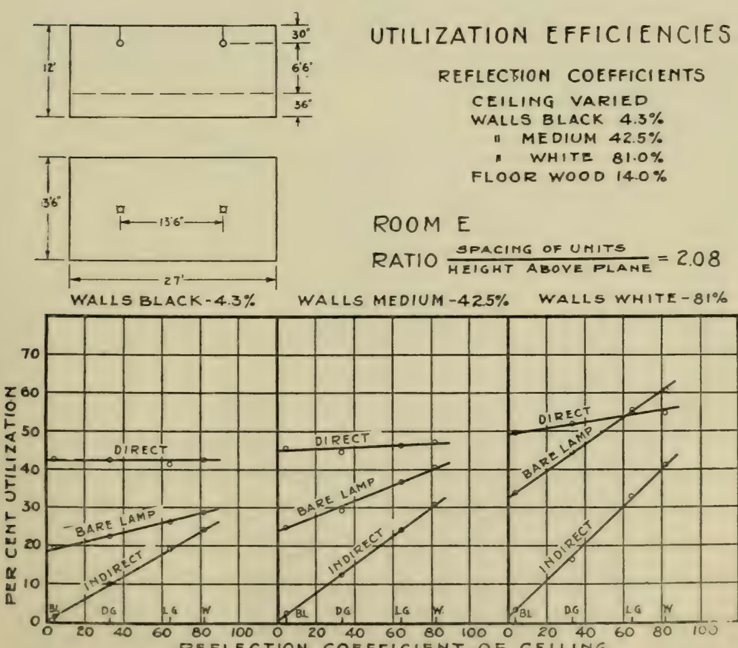
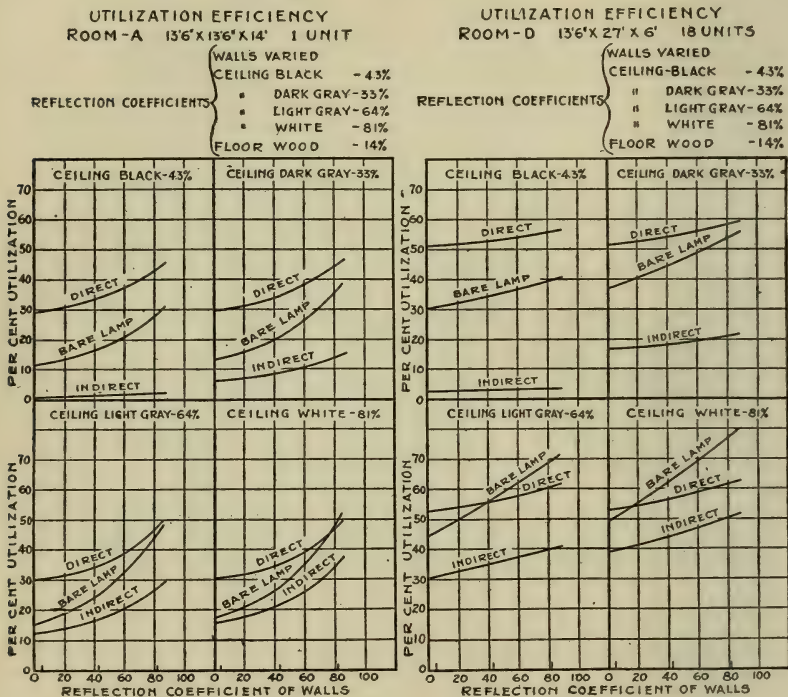

UTILIZATION EFFICIENCIES
REFLECTION COEFFICIENTS
CEILING VARIED
WALLS BLACK 4.3%
" MEDIUM 42.5%
" WHITE 81.0%
FLOOR WOOD 14.0%
ROOM E
RATIO SPACING OF UNITS / HEIGHT ABOVE PLANE = 2.08
30"
6'6"
36"
12'
13'6"
27'
WALLS BLACK-4.3%
WALLS MEDIUM-42.5%
WALLS WHITE-81%
PER CENT UTILIZATION
DIRECT
BARE LAMP
INDIRECT
BL
D.G
L.G
W
REFLECTION COEFFICIENT OF CEILING

Fig. 14.



Figs. 15 and 16.

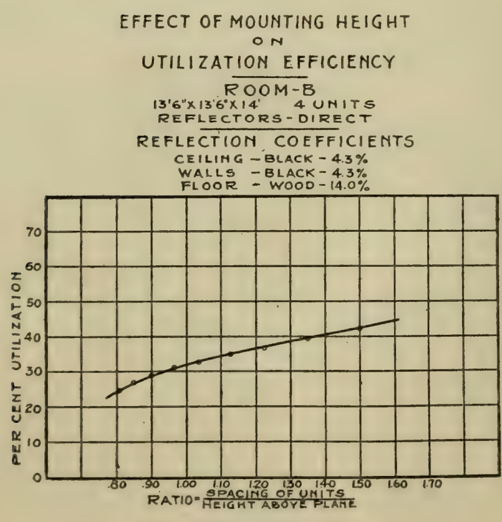


Fig. 17.

Comparisons of the three types of lighting units on the basis of the absolute values of the utilization efficiencies are to be discouraged because of the many important factors which are neglected in such a comparison. For example, in some combinations the bare lamp distribution actually gives the highest utilization efficiencies but in practise the lamp would necessarily be enclosed in diffusing glassware and the consequent absorption loss of at least 20 per cent. of the light would dissipate its apparent advantage.

In the tests the reflectors were not always placed at the height which would result in the maximum illumination with reasonable regard for uniformity, but the same proportion was held as in an ordinary installation. The curve of Fig. 17, plotted from test results in a small room with dark walls and ceiling, indicates the gain in utilization efficiency for steel reflectors when the spacing ratio is changed from 0.8 to 1.6. In the comparative tests made in this room the selected height of the units gave a spacing ratio of 1.04, though for the steel reflectors the higher efficiency possible with a lower mounting height can be obtained without seriously effecting the uniformity.

TABLE IV.

Room	No. units	Spacing ratio	Walls and ceiling	Ratio, $\frac{\text{Maximum illumination}}{\text{Minimum illumination}}$ Bare lamp	Direct	Indirect
A	1	1.59	Black	2.33	2.56	1.54
			White	1.45	1.76	1.34
B	4	1.04	Black	1.80	1.93	1.64
			White	1.24	1.26	1.29
C	8	1.56	Black	2.03	2.78	2.07
			White	1.30	1.69	1.43
D	18	2.08	Black	1.86	1.69	1.89
			White	1.09	1.32	1.28
E	2	2.08	Black	3.64	4.52	2.20
			White	1.69	2.83	1.58

The variations in the illumination, as expressed by the ratio of the maximum to the minimum test station value, are shown in Table IV for some representative conditions. The variations are of course more pronounced in the dark wall combinations and in general are greater for the direct system than the others. It is worthy of note, however, that where the variations exceeded a 2 to 1 ratio, the corner test station value was from 20 to 50 per cent. lower than any other. Disregarding this station in computing the variation for these extreme cases, therefore, a

more satisfactory degree of uniformity than indicated by the values of the table is found to exist in the useful portion of the room.

Inspection of the utilization efficiency curves plotted from the test results indicates that in every case with dark floors where a change is made from a dark to a lighter ceiling the *added* light is directly proportional to the reflection coefficient of the ceiling; this holds both for the indirect lighting where the illumination is almost entirely dependent upon the shade of the ceiling and for the direct reflectors where the total increase due to the ceiling may be only a few per cent. Considered in another way, the change is a first degree variation, for no important portion of the useful light is reflected by the ceiling more than once.

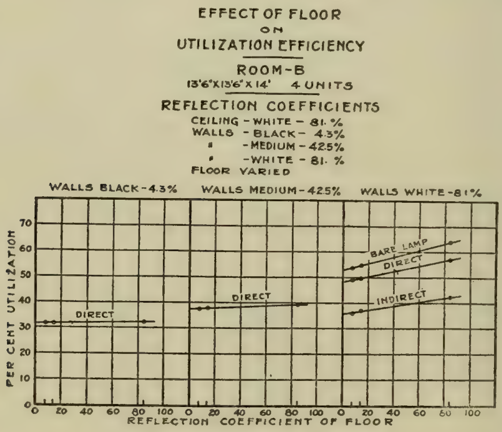


Fig. 18.

Where illumination values are plotted against variable shades of wall, on the other hand, it is seen that the useful light increases more rapidly than the wall reflection coefficient and this effect is magnified in the rooms with comparatively high walls. This can be expressed by the statement that much of the light which strikes the side walls undergoes multiple reflection before reaching the test plane. The second or higher power of the reflection coefficient is therefore involved, and hence the curve cannot be a straight line function, though this assumption has been made in some early investigations on this subject.[6]

[6] For further discussion see Appendix.

Tests with varied floors in the small room, results of which are given in the curves of Fig. 18, and in Table V, indicate that light floors do not increase the utilization efficiency appreciably except when combined with light walls and ceiling. Tests with light floors are to be run later in the larger room also.

TABLE. V.—COMPARATIVE UTILIZATION EFFICIENCIES BASED ON BLACK FLOORS AS 100 PER CENT. (VALUES FROM ROOM "B" TEST CURVES,—DIRECT REFLECTORS.)

		Floor coefficient		
Ceiling	Walls	Black 7.6 Per cent.	Oak 14 Per cent.	White 84 Per cent.
White	Black....	100	100.2	101.7
	Medium	100	100.4	103.5
	White	100	101.5	116.5

Tests on the three types of lighting units showed that, as one would expect, the increase was practically the same for the three forms of distribution, consequently the remaining floor tests were run with one type of unit only. In the usual practical installation, the floor may be considered to be dark but the values shown for white floors are nevertheless interesting in that they account for the unusually high efficiencies that have sometimes been obtained in tests of equipment in new structures, sanitary lunch rooms, and the like where walls, ceilings, and floor are all light in color.

APPENDIX.

TEST METHOD.

Changes in the test set up were made in the order which involved the smallest time requirement. For instance, tests for the three types of units for given walls and ceiling were run in succession, as reflector changes were most easily accomplished. On the other hand, alterations of the ceiling covering required the most time and in consequence all combinations for a single shade of ceiling were tested before the ceiling was changed. The comparisons of test results on the three units, under this method of procedure, extend throughout the entire series. This is also true for the different walls since the three changes are made for each ceiling shade. The ceilings were used in the order of black, white, dark gray and light gray to detect immediately any progressive error which might otherwise continue undiscovered if the ceilings were taken in the order of their reflection coefficients.

The possibility of errors through variations in the test lamps was obviated by the special care taken in their selection and rating. Measurements showed that the maximum variation from the average light center length was less than one eighth inch (3.17 mm.). The entire selection, which consisted of nearly double the number of lamps required, was aged the equivalent of 50 hours burning at normal voltage before the ratings were made. Laboratory precision photometers were used for the candlepower measurements. Mean spherical candlepower was observed in an Ulbricht sphere. These measurements were checked by horizontal candlepower ratings on a bar photometer and by point by point distribution curves on specimen lamps. Because of the uniformity in the manufacture of the lamps and the large number selected for the original lot it was possible to obtain groups of lamps for the tests whose maximum variation in lumens output at a given voltage was less than 1 per cent.

Although the 100-watt gas-filled lamps were commercially rated at 1,257 lumens and the 40-watt vacuum lamps at 384 lumens, the larger lamps were photometered and used at 1,000 lumens and the smaller ones at 333 lumens. Color differences in photometry were very largely eliminated at the lower efficiencies. A second important consideration was that the depreciation in light output during the course of the tests could be minimized by operating the lamp at 5 to 10 per cent. less than normal voltage. The lamps were photometered upon the completion of half of the series of tests and at the conclusion. The average decrease in light output was found to be less than 1 per cent. for the full time.

The fluctuations in light output, which are almost inevitable when lamps are supplied from an ordinary lighting circuit, were entirely avoided by using current from storage batteries with rheostats connected in series to regulate the voltage supplied to the test units.

The voltage drop from the center of the ceiling network to each socket for the separate arrangements of units was carefully determined and checked before the start of the tests. The greatest variation found between individual sockets in any arrangement used was less than 0.3 volt. During the tests the voltage was maintained at the center of the network at such a value that the

average socket voltage was that at which the lamps generated the specified flux. Calibrated laboratory standard voltmeters were used to check the voltage drop to the sockets and to indicate the proper voltage during the tests.

Test lamps were burned only during the time when photometric observations were being made. Two auxiliary lamps of 300-watts each, operated from the regular lighting circuit, furnished the illumination necessary for carrying on the work of changing the set ups. Units of this large size were chosen in order that there might be no possibility of the lamps being inadvertently left turned on during tests.

The test room was entirely clear except for a black wooden photometer bench approximately 2 ft. (0.60 m.) wide and 3 ft. (0.91 m.) high which projected into one corner of the long room as shown in the floor plan of Fig. 9. In the square room it terminated just at the corner though the aperture in the wall at that point remained. The interior which surrounded the experimental test room was a large photometric laboratory which was kept dark during the time of the tests in order to eliminate the possibility of stray light entering the test room.

The minimum number of photometric settings required at each station under the conditions of the test series was determined as follows: A number of tests were made with five readings per station. Five tests selected at random from the results of each of the spot readers, indicated that the maximum variation between the test average, calculated from five readings per station, and from the first three readings, was less than 0.2 per cent. for either spot reader. Further reduction in the number of readings to two per station, while not affecting the average results to an important extent, did not secure any valuable economy, as the time required for the actual photometric observations was a small fraction of the total. In all tests, therefore, the average of three photometric settings was used for the value of the illumination at each station.

The portable photometer was carefully checked at the beginning of each test period against two or more rotating standard lamps. Its constancy during the period was insured by frequent comparisons against an auxiliary checking standard. To further

insure constancy of the results, the last test performed by each shift in a working period was checked by the other shift at the beginning of the next test period, and if close agreement was not found the source of difference was discovered before further tests were undertaken.

Because of the importance of an accurate indication of the current in the photometer comparison lamp, the small portable meter commonly used with the Weber photometer was discarded in favor of a laboratory standard millivoltmeter and current was supplied from a 100-volt battery through a three point rheostat, with an auxiliary rheostat for close regulation. The large scale of the meter and the entire steadiness of the current supply contributed to easy and precise control.

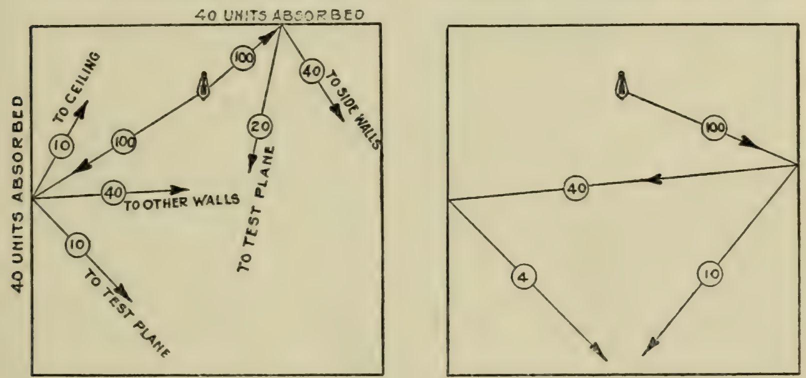
COMPARISON OF INCREASE OF UTILIZATION EFFICIENCY DUE TO LIGHT WALLS AND CEILING.

A simple example will serve to illustrate why the increase in utilization efficiency with light walls does not follow the same law of direct proportion which the test results indicate for light ceilings. The diagrams of Figs. 19, 20 and 21 show a cubical room with walls and ceiling of 60 per cent. reflection coefficient and a dark floor. It is assumed, first that the side walls receive 100 units of light from the source, and in the second case, that the ceiling similarly receives 100 units.

Of the light incident upon the wall, 40 per cent. is absorbed and the remainder is reflected to the other surfaces which define the limits of the room. In order to simplify the analysis it is assumed that the light reflected to the opposite plane is twice that which reaches any adjacent surface. Therefore, ten units of light reach the test plane from this first wall reflection and forty units are directed to the other side walls. The latter quantity is again reflected in the same percentages. Thus four units, or 40 per cent. of the light utilized from the first wall reflection must be received at the test plane from the second wall reflection.

In the second case, 20 units are directed to the test plane from the 100 units incident upon the ceiling. On the basis previously considered, four of the forty units which strike the walls are reflected back to the ceiling. Twenty per cent. of this, or 0.8 unit, is then reflected to the test plane. Therefore, the second ceiling

reflection adds only 4 per cent. to the useful light received from the first reflection. In other words, the succeeding reflections are found to be roughly ten times more important in the case of the side walls than for the ceiling, and this accounts for the marked curvature of the plots of utilization efficiencies with vari-



Figs. 19 and 20.

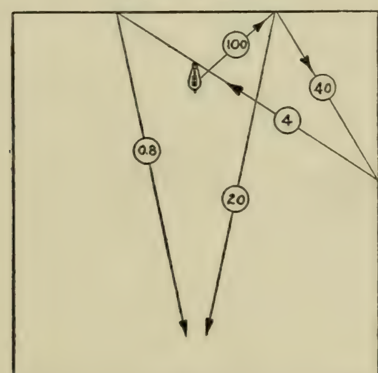


Fig. 21.

able wall coefficients, in contrast with the straight lines which express the results with variable ceiling shades.

TABLES OF UTILIZATION EFFICIENCY.

The utilization efficiencies found in the individual tests are arranged in the following tables which form the basis of the curves plotted in Figs. 10 to 16. For some purposes the tables supply a more convenient method of comparison than the curves. However, the latter furnish more consistent comparisons since the variations between individual tests, especially marked in the

direct reflector tests because of the large effect of slight changes in reflector adjustment, are eliminated in the plotted results.

Room A 13′ 6″ x 13′ 6″ x 14′ high (4.11 x 4.11 x 4.26 m.).
1 unit.
Height above plane 8′ 6″ (2.59 m.).
Test plane 36″ (0.91 m.).

Ratio, $\frac{\text{Spacing of units}}{\text{Height above plane}} = 1.59.$

Oak floor.

TEST UTILIZATION EFFICIENCIES.

Walls	Ceiling: Black	Dark gray	Light gray	White
Bare lamps.				
Black	11.7	13.2	16.1	17.7
Medium	17.1	20.6	25.3	27.1
White	28.8	35.2	44.8	48.8
Direct.				
Black	30.2	29.3	29.9	30.1
Medium	34.6	34.1	34.5	34.8
White	44.7	44.0	46.8	47.6
Indirect				
Black	0.93	7.0	12.8	16.1
Medium	1.5	9.1	16.7	21.3
White	2.7	13.8	26.8	34.7

Room B 13′ 6″ x 13′ 6″ x 14′ high (4.11 x 4.11 x 4.26 m.).
4 units.
Height above plane 6′ 6″ (1.98 m.).
Test plane 60″ (1.52 m.).

Ratio, $\frac{\text{Spacing of units}}{\text{Height above plane}} = 1.04.$

Oak floor.

TEST UTILIZATION EFFICIENCIES.

Walls	Ceiling: Black	Dark gray	Light gray	White
Bare lamps.				
Black	13.0	15.2	17.6	18.8
Medium	19.7	23.3	28.1	30.3
White	31.9	39.7	49.5	54.7
Direct.				
Black	31.4	31.4	31.6	31.7
Medium	35.5	36.8	37.2	37.9
White	43.8	45.8	48.5	49.8
Indirect.				
Black	1.0	6.7	11.8	15.1
Medium	2.2	9.4	17.4	21.7
White	4.5	15.2	29.1	37.0

Room C 13′ 6″ x 27′ x 9′ high (4.11 x 8.22 x 2.74 m.).
8 units.
Height above plane 4′ 4″ (1.32 m.).
Test plane 36″ (0.91 m.).
Ratio, $\frac{\text{Spacing of units}}{\text{Height above plane}} = 1.56.$
Oak floor.

TEST UTILIZATION EFFICIENCIES.

Walls	Ceiling: Black	Dark gray	Light gray	White
	Bare lamps.			
Black	23.0	27.3	32.6	36.2
Medium	28.9	36.5	44.8	46.8
White	37.8	48.3	59.7	67.4
	Direct.			
Black	45.0	43.5	45.1	44.1
Medium	46.7	48.5	49.8	49.1
White	50.6	52.4	56.4	57.2
	Indirect.			
Black	1.9	12.1	22.7	28.9
Medium	2.5	14.9	28.8	35.4
White	3.5	18.0	35.7	45.4

Room D 13′ 6″ x 27′ x 6′ high (4.11 x 8.22 x 1.82 m.).
18 units.
Height above plane 2′ 2″ (0.66 m.).
Test plane 36″ (0.91 m.).
Ratio, $\frac{\text{Spacing of units}}{\text{Height above plane}} = 2.08.$
Oak floor.

TEST UTILIZATION EFFICIENCIES.

Walls	Ceiling: Black	Dark gray	Light gray	White
	Bare lamps.			
Black	30.1	37.3	45.7	49.9
Medium	34.5	44.9	57.0	62.8
White	41.1	53.0	68.0	77.2
	Direct.			
Black	51.4	50.0	53.5	53.1
Medium	52.6	54.5	57.8	55.2
White	58.0	56.1	59.8	61.9
	Indirect			
Black	2.8	16.5	31.4	39.5
Medium	3.0	17.8	35.6	44.2
White	3.5	19.9	39.2	51.3

Room E 13′ 6″ x 27′ x 12′ high (4.11 x 8.22 x 3.65 m.).
2 units.
Height above plane 6′ 6″ (1.98 m.).
Test plane 36″ (0.91 m.).

Ratio, $\frac{\text{Spacing of units}}{\text{Height above plane}} = 2.08.$

Oak floor.

TEST UTILIZATION EFFICIENCIES.

Bare lamps.

	Ceiling			
Walls	Black	Dark gray	Light gray	White
Black	19.4	22.5	26.3	28.8
Medium	25.0	29.6	36.4	40.4
White	33.8	44.6	55.5	60.4
Direct.				
Black	42.6	42.7	41.7	42.7
Medium	45.7	44.7	46.6	47.3
White	49.9	52.0	54.9	54.9
Indirect.				
Black	1.5	10.0	19.1	24.2
Medium	2.2	12.4	24.2	30.6
White	3.1	16.5	32.9	41.0

DISCUSSION.

MR. L. C. PORTER: In the curve shown on the seventh page, for the indirect unit, I notice that the distribution is rather narrow and I should like to ask if there were sufficient units to illuminate the ceiling uniformly? If not, what difference would this make? On another page, regarding the light coming from the ceiling through multiple reflection, it is said, "Considered in another way, the change is a first degree variation, for no important portion of the useful light is reflected by the ceiling more than once." In ordinary rooms in which there are tables in service, particularly in rooms where the tables are covered with white cloths, wouldn't there be considerable proportions of the light which would come down through multiple reflection from the table surfaces?

MR. T. W. ROLPH: Fig. 17 shows the increase in the utilization efficiency obtained by increasing the spacing of the units, or the distance between units as compared with the height above the plane of illumination; the curve shows a steady increase in

illumination efficiency from the spacing of 0.8 to 1.6. That is in Room B. In the test results given on Room B, the spacing constant is only 1.04. Therefore by increasing the spacing or decreasing the height, an appreciably higher efficiency would be obtained, and this is further emphasized by the fact that the distribution curve, as shown in Fig. 6, is the distribution curve of a reflector designed for spacings of about 1.6 to 2. It occurs to me that it would be better practise, and fairer to the reflector to use the intensive form of distribution on the spacing used or else to use a wider spacing with the curve which is used in these tests.

I think that the data contained in this paper will be of great value in illumination design and it is to be hoped that the authors will have the opportunity to carry the work further to semi-indirect and translucent direct light units.

Mr. J. R. Cravath: One thing which the paper has brought out has been known for a long time, but perhaps has not been brought out forcibly as this paper brings it out, and that is the important effect of wall absorption on the efficiency. Not only is the wall absorption important from the standpoint of efficiency, but when we consider the matter from the standpoint of eye comfort and the best conditions for the eye, it is equally important that we do not view our lighting units against a dark background; in other words, the lighter the walls, the better the conditions are likely to be for the eye, irrespective of the purely physical efficiency. I have also noticed the high results that Mr. Harrison speaks of on tests made in rooms with light colored floors.

Mr. Earl A. Anderson (In reply): In his discussion Mr. Porter inquired regarding the possible effect of the narrowness of the distribution curve shown in Fig. 7 for the 40-watt indirect fixture used in these tests. The appearance of the ceiling when illuminated by this system is illustrated in the photograph of Fig. 3. The room with 18 outlets was the only arrangement in which the 40-watt equipment was tested. In choosing the indirect fixtures the major requirement was a distribution which directed the entire light flux on the ceiling area. It so happens that the reflectors are slightly more concentrating than necessary at the close mounting involved in this room proportion. Con-

sidering the distributed system of a large number of units, however, it is not probable that the variation in ceiling illumination is sufficient to affect the utilization efficiency appreciably.

Mr. Rolph's comment referring to the possibility of higher efficiencies in room B arrangement by the use of reflectors of another distribution characteristic is entirely true. However, the variation in utilization due to changes of room dimensions and wall reflection coefficients formed the prime object of the series of tests. In order to obtain entirely comparative results on this basis it was necessary to use a similar distribution throughout the room arrangements even though this distribution would not represent the best practise in every instance.

It is to be borne in mind that the curve of Fig. 17 referred to by Mr. Rolph is rather an extreme case in that side walls and ceiling were dark; with light walls the absorption effect is of course smaller and the difference in efficiency at varied spacing ratios is less marked.

Mr. Porter has suggested the possibility of a large amount of multiple ceiling reflection due to white covered cloth tables or other light objects in the room. The discussion in the paragraph from which quotation is made is specifically limited to rooms with dark floors, which interpreted broadly would eliminate any case in which a surface of high reflecting efficiency was located beneath the lamps. Tests indicate that in rooms of the proportions of "B" the maximum increase in measured illumination where a white floor is used is about 15 per cent.

Subsequent to the preparation of the paper the increase due to white floor covering was tested in the large room C which has 8 outlets. The results for the series are given in Table VI below.

TABLE VI.

		Floor Coefficient		
Ceiling	Walls	Black 7.6 per cent.	Oak 14 per cent.	White 84 per cent.
Black	White	100	101.	107.0
Dark Gray	White	100	101.7	115.0
Light Gray	White		102.5	123.5
White	Black	100	100.3	108.5
	Medium	100	101.1	115.3
	White	100	103.1	129.0

As anticipated the increased utilization due to white floors is found to be more important in rooms with comparatively large floor dimensions in relation to the height. In fact, the maximum increase determined from the tests in this room is nearly twice that for the small high ceiling arrangement.

DIFFUSING MEDIA—PROJECTION AND FOCUSING SCREENS.*

Synopsis: The distribution curves and efficiencies of various wall and cloth coverings, mirrors and special preparations used as projection screens are given. The properties of the ideal screen are discussed. Data are given on diffusing transmission screens for focusing and projection.

PROJECTION SCREENS.

Projection screens vary from mat white walls and cloth screens to special surfaces and coverings intended to concentrate the light within a narrow angular field. With an abundance of light, there is no question but that the highly diffusing surface gives a minimum of eye discomfort. However, the question of obtaining sufficient illumination must be considered on account of the expense and difficulty of operation of intense sources and the liability of injury to the projected material where excessively high illumination is used.

Numerous attempts have been made to increase the efficiency of projection screens by increasing their reflecting power and by so designing them that the reflected light is nearly all concentrated within an angle of 30° from the normal. Some of these specially prepared screens, however, produce considerable eye discomfort, hence the problem of selecting the best possible screen is very complex. We shall first discuss the reflection analyses of various types of screens in use, then the ideal screen, then the maximum realizable efficiency. When not otherwise specified, the loss by absorption is assumed to be about 20 per cent.

The following data was all taken with a disk source subtending a solid angle of 0.01 steradian and perpendicular illumination. The readings are reduced to that of a perfectly diffusing surface having 100 per cent. reflecting power under the same illumination.

* Report No. 8, I. E. S. Committee on Glare, 1914-15.

Angle of observation	0°	1	3	5	7	10	15	30	45	60°
1. Magnesium carbonate block	0.875	—	—	87.5	—	0.875	0.875	0.832	0.716	0.675
2. Magnesium oxide	0.80	—	—	0.80	—	0.80	0.80	0.77	0.75	0.66
3. Mat photographic paper ...	0.78	—	—	0.78	—	0.78	0.78	0.78	0.76	0.72
4. White blotter	0.76	—	—	0.76	—	0.76	0.76	0.73	0.70	0.67
5. Pot opal, ground	0.69	0.69	0.69	0.69	—	0.69	0.69	0.68	0.66	0.64
6. Flashed opal, not ground ..	11.3	11.3	11.3	0.31	—	0.22	0.215	0.205	0.200	0.175
7. Glass, fine ground	0.29	0.29	0.29	0.29	—	0.27	0.20	0.14	0.13	0.12
8. Glass, coarse ground	0.23	0.22	0.21	0.20	—	0.19	0.16	0.11	0.11	0.12
9. Mat varnish on foil	0.83	—	0.775	0.715	0.655	0.615	0.49	0.28	0.21	0.16
10. Mirroroid A (Al)	1.01	—	0.94	0.85	0.76	0.66	0.52	0.25	0.15	0.12
11. Mirroroid B (Al)	1.18	—	1.12	1.04	0.95	0.87	0.71	0.28	0.16	0.12
12. Becker compound	1.93	—	—	1.80	—	1.70	1.53	0.83	0.38	0.30
13. Mirror with ground face ...	4.9	—	—	4.55	—	3.86	3.03	0.78	0.42	0.35

The magnesium carbonate block (1) was freshly scraped with a sharp straight edge leaving no visible pits or furrows. The magnesium oxide (2) was deposited on the white card from burning magnesium ribbon. The mat photographic paper (3) is of interest as being (with 5) the nearest perfectly diffusing reflector on the list. It is a calendered stock covered thinly with minute crystals. The solid opal ground (5) is lower in reflecting power but very permanent and can be cleaned by washing indefinitely. Ground glass (7 and 8) is of interest in connection with its use as focusing and diffusing screens (v. infra).

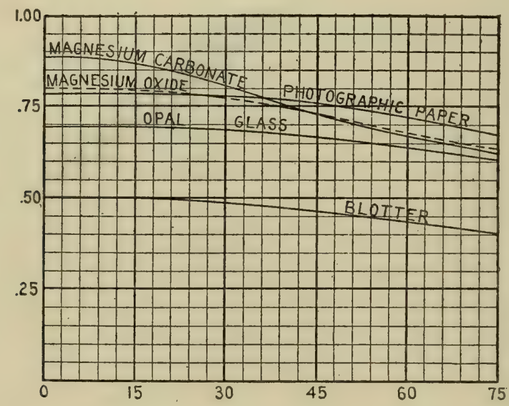


Fig. 1.—Distribution curves of nearly mat screens.

No. 9 is a patented screen of high repute consisting of tin foil on a suitable support, varnished with a special diffusing varnish. It is highly selective, but not very efficient and deteriorates with age. The mirroroid screens A and B are filled fabric painted with aluminum paint. B is on a finer grained smoother fabric than A. Numerous screen materials of this type are on the market under various names, all giving very similar distribution curves.

No. 12 is an experimental screen, prepared in an attempt to excel the ordinary aluminum screens. It possesses exceptionally high reflecting power, efficiency and durability.

No. 13 is an ordinary silvered mirror which has been fine ground on the front surface. Its efficiency is extremely high, near

the theoretical limit, in fact, and brighter than the best reflecting, highly diffusing surface available out to an angle of 25° from the normal and five times as bright in the middle angles.

A large percentage of the projection screens in use are far below maximum efficiency; a slight accumulation of dust will lower the efficiency 50 per cent. Many roller screens of painted cloth of the non-selective type reflect under 40 per cent. when new—at least 70 per cent. is easily attainable in this type of screen.

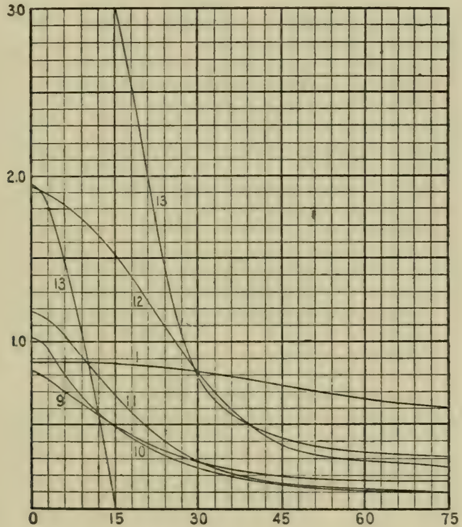


Fig. 2.—Distribution curves of special screens.

The more important of these reflection curves are reproduced in Figs. 1 and 2. Fig. 1 includes the flatter curves, Fig. 2 those of the special screens plotted to half the scale. The curve for No. 13 is in two sections.

Efficiency in Projection Screens.—If an ideal screen be taken to be one which reflects all the light projected upon it, uniformly within a given angle (say 30°) from the normal, then a rational measure of diffusion efficiency in any screen is the ratio of the light reflected within this angle to the total light reflected. To obtain the light reflected within a given angle, multiply the ordinates of the brightness curve (such as are plotted in Figs. 1 and 2) by $2\pi \sin \alpha \cos \alpha$ and integrate out to the angle desired.

Calculating thus, the 30° diffusion efficiency, total reflecting power and 30° total efficiency of some of the screens are calculated from the data given above.

Screen	30° diffusion efficiency	Reflecting power	Total efficiency
No. 1 Magnesium carbonate block....	0.25	0.87	0.22
No. 10 Aluminum paint, mirroroid B ..	0.55	0.25	0.14
No. 12 Becker compound	0.54	0.63	0.34
No. 13 Ground mirror	0.69	0.92	0.64
Ideal screen (see below)	0.90 to 1.00	0.92	—

The reflecting power given is the ratio of total reflected to total incident light. Total efficiency is the ratio of the light reflected within 30° of the normal to the total incident.

As may be seen from the table, even the frosted mirror reflects considerable light at angles greater than 30°. Though the brightness at these large angles is low, the whole solid angle is so large that considerable light is represented. The nearest possible approach to an ideal projection screen would probably be a mirror, the front face of which was composed of minute hexagonal facets, each of which was a concave mirror of just sufficient diameter to refract light at a maximum angle of 15° with the axis. This is the case when the radius of curvature of each lens is approximately equal to its diameter. Owing to the necessarily hexagonal form of each little lens, the angle of reflection would not be sharply limited.

Glare in Projection.—Discomfort in viewing projected images may be due to one or more of several causes; there may be excessive or deficient illumination, excessive contrast or veiling illumination, and there is always some displacement and some intensity flicker present in cinematographic projection. Displacement flicker is undoubtedly the chief cause of eye fatigue (largely muscular) in motion picture projection.

The problem of the proper average brightness in a projected image has not yet been properly studied but is probably in the neighborhood of half a lambert with a tolerance of a factor of five either way. The problem is complicated by the partial darkness accommodation of the retina. Too high an illumination produces brightness glare in itself and excessive contrast between parts of the image and between the picture and its dark surround-

ings. Too low illumination sacrifices details in the low lights and eye strain if the attention is centered upon those details.

Contrast within the picture is determined largely by that in the slide or film projected, that between the picture and its border (frequently of black velvet) by the relative reflecting powers of screen and border. Contrasts in the picture vary from 1 : 1 up to about 1 : 100; between picture and frame from 1 : 100 to very high values.

Veiling illumination comes from the general room lighting and from stray light from the projecting apparatus. Its effect is to lower contrast. If a general illumination V falls upon a picture when the contrast without it is $C = I_2/I$, then the contrast is reduced to $(I_2 + V) : (I_1 + V)$. In "daylight projection" I_2 and I_1 are so increased that V is still negligibly small compared with them and the same contrast is secured as with lower picture illumination and small veiling illumination.

When highly selective screens such as ground mirrors or screens painted with aluminum paint are used, stray light from the projecting apparatus must be carefully excluded since in this case such stray light is particularly effective in causing veiling illumination.

FOCUSING SCREENS.

In viewing a projected image by transmitted light an image of maximum brightness but one without any specularly transmitted light is desired. Screens are available which absorb but very little light and which diffuse the transmitted light nearly uniformly through either a small angle or through 180°. As a rule the ground and etched glasses diffuse through but 5° to 15° from the normal, the opal glasses through a hemisphere. The following data give the diffusion in typical materials:

Angle	F. O.	P. O.	F. G.	C. G.	E_1	E_2	E_3	O P
105	0.29	0.102	0.076	0.055	—	—	—	—
120	0.33	0.121	0.125	0.077	—	—	—	—
135	0.36	0.127	0.193	0.129	—	—	—	—
150	0.39	0.133	0.386	0.355	—	—	—	—
165	0.40	0.138	4.13	3.55	—	—	—	—
170	0.41	0.141	7.9	5.56	3.0	5.5	1.7	2.1
175	0.42	0.143	12.9	11.3	18.8	23.3	13.1	13.4
177	0.42	0.143	15.5	13.2	29.8	33.0	33.0	22.4
179	0.42	0.144	15.8	13.2	64.4	53.7	125.6	51.4
180	0.42	0.145	16.1	13.2	66.0	57.0	135.0	56.6

The brightness unit is that of a surface transmitting 100 per cent. perfectly diffusely through 180°. The flashed opal (about 0.1 mm. thick) and pot opal (about 2 mm. thick) in the first two columns give very high diffusion and are nearly non-selective. The fine ground (F. G.) and coarser ground (C. G.) glasses transmit chiefly within a small angle near the normal. E_1 is an etched, high grade focusing glass intended to concentrate the light within a small angle. E_2 and E_3 are similar, but are prepared by a special patented process which leaves the surface in very small shallow spherical cavities. These tiny negative lenses form images which may be viewed with a microscope. O. P. in the final column is oiled paper from a window envelope.

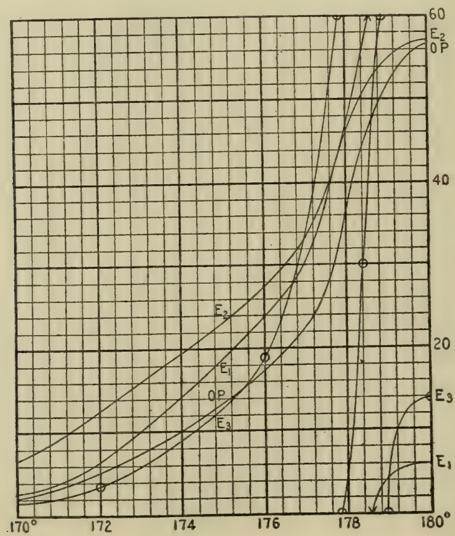


Fig. 3.—Focusing screens.

The fine ground glass (column 3, F. G.) had the same surface and was a part of the diffusing mirror for which data are given (No. 13) in the first table. It is to be noted that passing twice through the ground surface doubles the diffusion; that is, the mirror gives double the diffusion of the single transmitting surface.

The extremely high diffusion of opal even in very thin layers

is to be attributed to the fact that the diffusing particles (see Report No. 2) are of just the proper size to give maximum diffusion, namely, of the order of two or three light wave-lengths. This material is nearly completely diffusing in thickness as small as 0.1 mm. When ground to a thin wedge, it shows specular transmission in thicknesses up to about 0.05 mm.

NELSON M. BLACK,
J. R. CRAVATH,
F. H. GILPIN,
M. LUCKIESH,
F. K. RICHTMYER,
F. A. VAUGHN,
P. G. NUTTING, *Chairman.*

A METHOD OF STUDYING THE BEHAVIOR OF THE EYE UNDER DIFFERENT CONDITIONS OF ILLUMINATION.*

BY F. K. RICHTMYER AND H. L. HOWES.

Synopsis: The rate at which a reader can read ordinary print at various illuminations is proposed as a possible method of studying visual efficiency, fatigue, etc. Curves are given, showing differences between individuals. A marked depression of these curves is shown to result from reading under conditions producing glare. The paper is intended to call attention to the method rather than to the results herein described.

In its report on "Tests for Visual Efficiency" the 1913-14 Research Committee made the following statement: "Future work in this important field must initially, to a large extent, be concerned with the development and comparison of test methods . . ." It was with this in mind that the writers, some months ago, took up the study of the method herein described.

It is unnecessary to elaborate upon the deleterious effects of improper illumination, artificial or daylight, upon the human eye. The basic nature of these effects can never be known until we know more about the processes by means of which radiant energy is transformed into visual sensation. Practically no structural changes, temporary or permanent, are observed in connection with them. The injurious effects are manifested largely by impairment of functions, and it is therefore by means of functional tests that the problems connected with visual efficiency must be attacked.

Furthermore, in view of the complexity of the phenomena concerned, and of the indirectness by which they must be studied, it seems obvious that more than one method must be employed if substantial progress is to be made. The different factors which

* A paper presented at the ninth annual convention of the Illuminating Engineering Society, Washington, D. C., September 20-23, 1915.

enter into visual phenomena must be combined in different ways, and the results obtained by several different methods of study intercompared. If one method gives results difficult of interpretation, the results obtained by some other method may make them more intelligible.

One difficulty with all of the methods now in use, or apparently available for use in the immediate future, is a relatively low precision. Methods of study giving low precision can be made useful in quantitative work only by getting a large number of observations with many different individuals. This necessitates that any method so used shall be easy of operation, shall require little or no previous practise, and shall be reasonably rapid.

The present paper is a report on some preliminary tests of a proposed method of studying visual efficiency.

It was pointed out by Dr. Ferree that the visual acuity test needed the addition of a time element to make it effective when studying the depression of vision resulting from long continued work under artificial illumination. One of the obvious ways of combining the time element and visual acuity, in such a manner as to observe the action of the eye under actual working conditions, is to study the rate at which one can read print at different intensities of illumination.

The reader was required to read aloud a definite number of words as rapidly as possible, at several different illuminations. The time of reading was taken with a stop-watch by the reader himself. A second observer simultaneously read the photometer and controlled the illumination, without allowing the reader to know the illumination or the sequence in which illuminations were used. The intensity of illumination was read by a portable photometer. Each specimen to be read contained the same number of typewritten words promiscuously arranged, each word containing two syllables and six letters. There was exact similarity in the length and number of lines to be read. The eyes were rested for two minutes between each reading.

The room used for the tests had mat-white walls and ceiling, and was illuminated by a central indirect lighting fixture. A rheostat in series controlled the illumination. The room was 30 feet in length, by 18 feet in width, and 12 feet in height. There

were no shadows on the reading material, which was placed on a reading desk inclined 35° to the horizontal. The distance of the eyes from the print was maintained constantly at 18 inches by means of a rest for the forehead. The reader sat erect in a comfortable office chair.

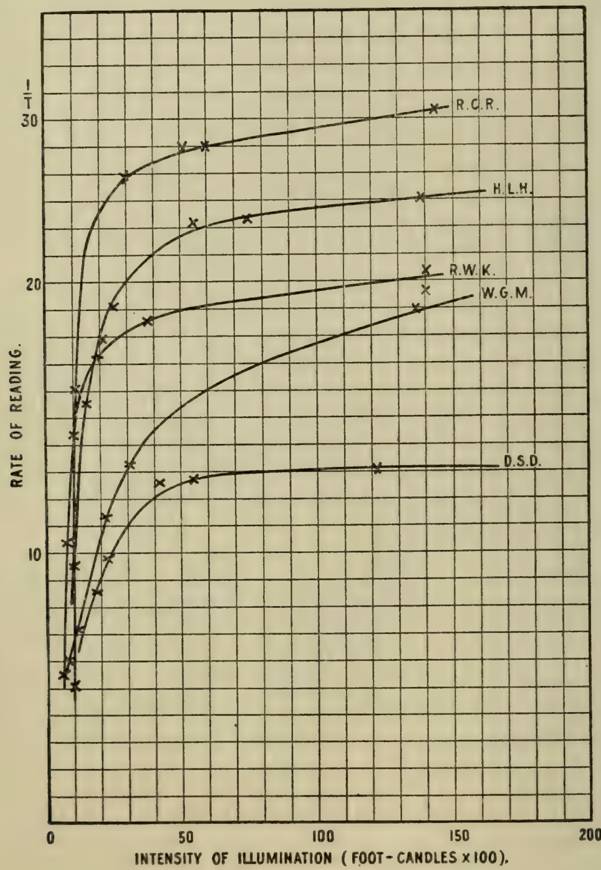


Fig. 1.

A brief study of Fig. 1 will serve to indicate the method of plotting the experimental data. The ordinates are proportional to the reciprocal of the time of reading, *e. g.*, "20" indicates that the time required to read the selection was fifty seconds. The abscissæ are proportional to the illumination, *e. g.*, "100" indi-

cates that the illumination was 1 foot-candle. In Fig. 1 are indicated typical curves for five different readers. It will be noted that all of the curves, if extended down to the axis of illumination, would have definite intercepts. This seems to indicate that the rate of reading would become zero before the illumination was reduced to zero. It will also be noted that all of the curves are similar in form, having the knee below ½ foot-candle. The uppermost curve represents an exceptionally high rate of reading. R. C. R. is a musician who has been accustomed to sight-reading music for fifteen years, and offers this as an explanation of his ability to read so rapidly. The curve marked H. L. H. is also above the average rate of reading, but very typical of the reader's curves. R. W. K.'s curve has the knee at a lower illumination than the others, and it is interesting to note in his case that he has very strong eyes and stated at the time that he experienced no fatigue during the tests. W. G. M.'s curve shows a less pronounced knee, and one which probably begins at a much higher illumination than the others. He stated at the time of reading that his eyes were in poor condition from night study. D. S. D. took great interest in the tests and endeavored to put the same amount of will-power into each reading. As a result he read more slowly, but obtained a typical curve.

All the men are graduate students in physics who are accustomed to using their eyes under fatiguing conditions. Although they differ greatly in temperament and previous scientific training, they seemed to require no practise worth mentioning in order to obtain the curves shown in Fig. 1. The remaining curves shown in this paper are the work of H. L. H.

It has been a matter of considerable interest to observe the effect on the working eye of substituting a frosted for a clear lamp in the direct field of vision; hence a 60-watt tungsten lamp was placed in front of the reader, 15° to the left of the line of vision and slightly below and beyond the desk. This caused the light to illumine the face of the reader without adding any direct illumination to the type. The illumination was, as usual, indirect, and this clear lamp was under control of the same rheostat as the indirect lamps. The curve representing these conditions is the lower one in Fig. 2. The clear lamp was replaced by a frosted

60-watt tungsten and the upper curve obtained. There is little gained by the use of the frosted lamp.

One of the earlier methods employed consisted of reading backward selected ten-line excerpts of the *Saturday Evening Post.* In order to make a merely cursory study of the effect of glare, suitable selections from that periodical were again used. A 40-watt clear tungsten lamp was placed 1 foot above the desk and in such a position that the light was strongly reflected up into the reader's eyes. Readings for a curve were taken, and then the indirect illumination was used through a similar range of intensities. In Fig. 3 the upper curve shows the indirect illumination reading; the lower the glare reading.

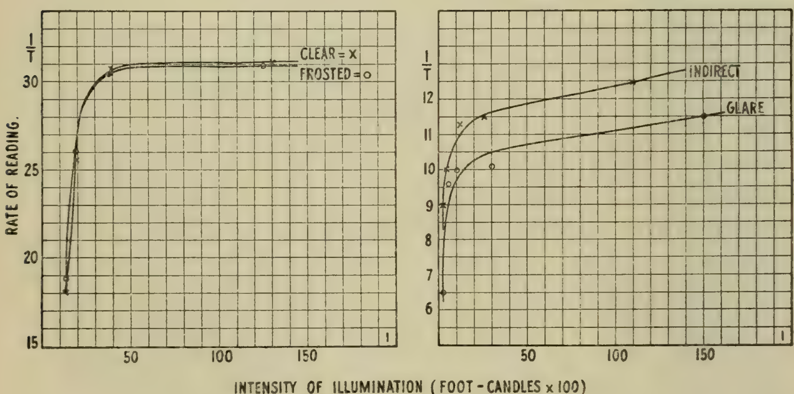


Fig. 2. Fig. 3.

These curves, taken under extremely opposite conditions, show the advantage of comfortable over uncomfortable illumination in the reading of ordinary print.

The following test shows some of the possibilities of the method:

The rate of reading was taken under a constant indirect illumination of 4 foot-candles, but with a lamp at various angles from the eyes, and in the field of vision. The lamp was kept 4 feet from the printed page, but at varying angles. It was allowed to shine in the eyes but not illuminate the print directly. In Fig. 4, —90° indicates that the lamp was at the extreme left, —60° that it was 60° to the left of the line of vision, etc., +90° indicating that it was 90° to the right of the line of vision. The total

illumination on the page tended to vary by 2 per cent. as the lamp was swung around, but was kept constant by the rheostat control of the indirect lighting. The rate of reading was taken eight times at each point and averaged. The readings were scattered, so as to avoid an increasing and unequally distributed fatigue effect, if present.

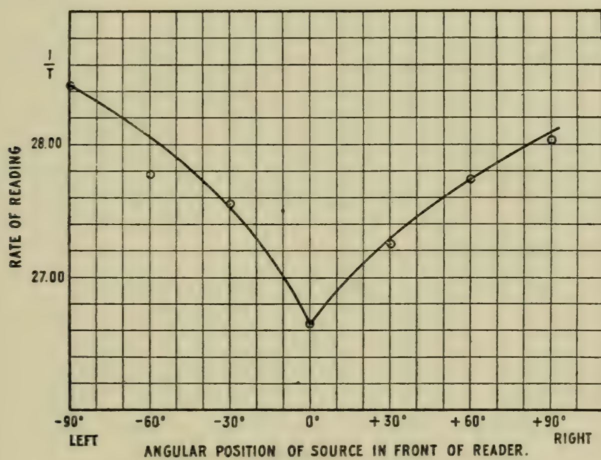


Fig. 4.

The curve shows that at $+90°$ or $-90°$ the lamp does not bother, but as it is moved nearer to the line of vision it is a source of annoyance. The discomfort increased very noticeably in passing from $\pm 30°$ to $0°$, *i. e.,* into the line of vision. Since the curve is plotted with an enlarged scale of ordinates, the effect is really small, and hence a delicate test of the limitations of the method is indicated.

The above results are presented not primarily, or perhaps at all, to call attention to the results themselves, but to indicate the possibilities of a method of studying visual efficiency. At present work is in progress to eliminate certain difficulties, to standardize conditions, and to ascertain to what extent it can be applied to the problem of eye-fatigue. The data, though not ready for publication, are extremely promising, indicating at least that the method is not only a natural one, but that it is capable of comparatively accurate quantitative results.

Photometrical Laboratory,
Cornell University, July, 1915.

DISCUSSION.

Dr. C. E. Ferree: I may be pardoned perhaps for pointing out that the test proposed by Drs. Richtmyer and Howes is not a new one. It has been used quite widely as a test of mental functions. It has been employed extensively, for example, as a test for mental fatigue; Geissler, Sharp and others have used it as a test for degree of attention; and Binet, the pioneer in the field of intelligence testing, employed it as a test for detecting the difference between imbeciles and the next higher grade of intelligence. Moreover, the confusing thing is that the workers in each of these fields (so remote from the one in which it is used in the foregoing paper) believe that they actually had a test for their particular purpose, and presented more or less convincing data in support of their beliefs.

I agree with the writers that a test to be effective for studying the depression of visual functioning as the result of a period of work, must combine the elements, visual acuity and time. I have grave doubts, however, about visual acuity being the dominant factor influencing rate of reading, or even being of sufficient importance to warrant serious consideration being given to rate of reading in the selection of a test method to indicate variations in acuity. For one thing, any performance in which the criterion for the task performed is recognition can not be considered an adequate or even a specific test for visual acuity. A letter or character may, for example, be recognized when it is not discriminated clearly,[1] and a very popular current method of teaching reading is based on the fact that words may also be accurately recognized without even attention being given to the individual letters. Indeed it was the realization of this fact that led us in the beginning of our own work to change the criterion employed in the conventional acuity test from recognition to the judgment of a space threshold,—the simplest and most repro-

[1] Tests have been conducted, for example, to determine how much of a letter or word need actually be present for recognition, and how much may be left out without even being noticed in the process of reading. This has been done by omitting parts of letters and words, leaving only enough to suggest the character of the whole. Any one who has performed such tests or knows the results that have been obtained will agree with me quite readily, I think, that recognition correlates very poorly with visual acuity. All that seems to be needed for recognition is a discrimination of some feature which may serve as a suggestion, and the remainder is filled out as a mental not a visual performance.

ducible of the sense judgments,—and to adopt a test object appropriate for this purpose.[2]

Supplementary to the consideration of the small part played by visual acuity in rate of reading is of course the large part played by other factors, the predominant influence of which is indicated both by the above discussion and by the history of the test. However, it is only fair to admit that a performance which is influenced by a number of factors may be used as a measure of the variations of only one if the influence of the others can be eliminated or held constant. Accordingly, the writers (Richtmyer and Howes), probably admitting the influence of other factors, want to use rate of reading as a measure of the variations in visual acuity produced by exposing the eye to different illumination effects for a period of time. The test they propose, however, is, I think, to be criticized in the following regards. (1) As stated above, clear discrimination is not necessary to reading and is not even present in reading done by a practised subject, especially in rapid reading. That is, the factor to be measured enters only to a comparatively small degree in the performance which has been selected as its measure. (2) They have not proposed a way of eliminating or holding constant the other factors (largely mental) which we have every reason to believe are strongly predominant in their influence on the performance. What they have done primarily is merely to change the application of the test from one field to another. To change the field of application is not, we scarcely need to point out, to change the nature of the test.[3] And (3) rate is a very inadequate and incomplete measure of any performance. Even

[2] The letters li in 8 pt. type, it will be remembered, were adopted as the test object after a wide canvass of possibilities, the test set to the observer being to determine and record how long in a given period of time the dot in the letter i is seen separated from the vertical line, which, as stated above, depends upon the judgment of a space threshold. The letter l was used in connection with the letter i for two reasons: (1) in order that a greater steadiness of fixation might be attained. (So small an object as the letter i alone does not give the maximum steadiness of fixation); and (2) in order that a standard might be had (an unbroken vertical line) in terms of which more accurately to judge the separateness of the dot from the vertical line in the letter i as the eye wavers in its attempt to hold a fixed adjustment.

[3] In devising our own test, for example, it was recognized that the conventional acuity test could not be applied unchanged to the measurement of fatigue. Numerous trials had shown that the results of the test were approximately the same after a period of work under unfavorable lighting conditions as they were before. In fact quite a radical change had to be made in the nature of the test before it could be applied to the measurement of fatigue.

if reading were a function of visual acuity alone, rate of reading would be an inadequate measure of the state of the eye with reference to its ability to see clearly.

In connection with its use as a measure of performance of mental function, rate of reading and the factors which influence it have received considerable experimental study. It may be of interest to the Society to have the following brief synopsis of the voluminous literature of the subject. The following individual differences have been shown in rate of reading. (1) Age. Up to a certain limit rate of reading increases with age. There is also a limit at which it decreases with increase of age. (2) Sex. It has been claimed by some investigators that women as a class read faster than men. This obviously, however, varies widely with the nature of the material read. (3) The mental status or condition of the subject. It has been found, for example, that in a given sex the mentally quick read faster than the mentally slow. (4) Mental habits and equipment. Habitual readers are as a class rapid readers. A study has been made also of the rate of reading of a single subject or individual. (1) It has been found, for example, that the speed with which reading is accomplished varies with the degree of attention that is given to the task. (2) There is a high coefficient of practise effect. Oehrn, for example, tested this by comparing passages read at the same hour and under as nearly as possible the same conditions on successive days for 8 days and found in case of six observers the gain due to practise to vary from 2.6 to 14.6 per cent. Sandiford claims that in the course of six years he varied his rate of light reading from 40 to 100 pages per hour. In both cases care was exercised to select passages presenting as nearly as possible the same difficulty of reading. For the same passage read a second time a gain in rate of about 10 per cent. has been found. Burt and Moore give the coefficient of reproducibility of rate of reading as about 81 per cent. (3) Speed has been found to vary with the kind of selection read with reference to length of words, meaning content, etc. Huey gives the following results for length of words making up the selection. Fifty letters spaced singly were read in 15.7 seconds; 50 four-letter words in 17.3 seconds; 50 eight-letter words in 19.5 seconds; 50 twelve-letter words in 28.5 seconds; and 50

sixteen-letter words in 54.1 seconds,—a difference of more than 300 per cent. in the time required to read words of different lengths. Another writer, Beer, finds that 200 one-syllable words require about 25 per cent. longer time for reading than 100 two-syllable words. Prandtl and others have studied the variability with the meaning and content and have found as might be expected a strong influence. (4) Speed has been found also to vary strongly with the degree of mental and bodily fatigue, with the speed and accuracy of eye movement, etc. With regard to the latter factor, for example, it has been shown by records of movement that the eye in traversing a line does not move continuously, but progresses by short movements and stops. That is, the content of the line is grasped by rapid changes of fixation. Obviously, therefore, the speed and accuracy of making the movements needed to give the most advantageous changes in fixation are a factor in rate of reading. We need not go further perhaps to show that the literature on the subject of rate of reading is extensive. The citation of the various items covered in this literature is of no importance here perhaps further than to demonstrate how variable a performance is rate of reading, and how improbable it is that visual acuity is the dominant factor by which it is influenced. In fact it is obvious that a very low correlation, if any, obtains between the greater number of the factors mentioned above and visual acuity. The influence of some of these factors is of course reduced by the conditions under which the writers have worked, but at best, rate of oral reading must be influenced by a very large group of mental functions; by all of the factors which influence the functioning of the eye with regard both to acuity and rate and accuracy of movement; and by those which impede or accelerate the motor co-ordinations concerned in rapid speech. Indeed, therefore, if fear should be expressed, as has been the case in previous meetings, that the results of our test* in which the performance is the judgment of a space threshold, the simplest and most reproducible of the sense judgments, are too much influenced by factors which are extraneous to the conditions to be tested, certainly much greater fear should be felt in that connection for this test

* See papers by C. E. Ferree and G. Rand in vols. VIII and X of the I. E. S. TRANS.

in which the performance is much less narrowly reduced to a function of a single factor.

I further agree with the writers that cumulative evidence both from our test and from several tests if possible should be collected before final conclusions are drawn; but caution should be exercised that the methods employed are tests for the same thing. Results should not, for example, be ascribed to the eye until it is pretty clearly established that they belong to the eye, nor should the results of tests for different functions be compared in drawing conclusions with reference to a single function. It may be a very useful thing to know how rate of reading is affected by different conditions of lighting, but I have serious doubts whether the results can be ascribed very narrowly to the eye. But if reading is to be used as a criterion for the selection of lighting conditions regardless of what function or set of functions is affected, a better measure of the performance should be chosen than the rate alone; also its usefulness must be evaluated as is that of any other criterion, namely the performance must show a sufficiently high sensitivity to change in the conditions to be tested, and it must have a satisfactory degree of reproducibility under any given condition, *i. e.*, the mean variation must fall well within the variation that is produced by the change in the condition to be tested. Unfortunately no data on the latter point is supplied in the advance print of the paper. Since the meeting, however, data have been very kindly submitted to me for Fig. 4 which I understand will appear in the final print. This figure is constructed to show the effect of seven different positions of a light in the field of view. The data are based on four observations for each position of the light. In four out of the six chances thus afforded for a comparison, the mean variation for the four observations is shown to be higher than the variation produced by changing the position of the light. Similar comparisons can not be made for Figs. 1 and 3 for the results shown in these figures are, I am informed, based only on one observation each.

I wish in conclusion to call attention to one point with regard to the control of conditions exercised by the writers in making their tests. There is no evidence in their statement of conditions

that in testing the effect of different intensities of light on the rate of reading they allowed the eye to reach a stationary state of adaptation or sensitivity to each intensity of light before the task chosen as the test was begun. The effect of state of adaptation of the eye on acuity is too well known to need more than mention here. It seems incredible that a satisfactory degree of reproducibility could be attained in any performance depending to any great extent on acuity in which the state of adaptation of the eye is not subjected to control. Moreover, without control results may not be representative of the performance of the eye working at that intensity,—being too much dependent upon the intensity of light to which the eye was exposed before the test was begun.

F. K. Richtmyer and H. L. Howes (Communicated): The writers feel that they must take issue with Dr. Ferree in the statement that the proposed test is outside the field of eye-fatigue testing. It is true, the rate-of-reading method has been used for various purposes in numerous psychological investigations. But *rate-of-reading as a function of quality and intensity of illumination* has not, so far as the writers know, been used for testing imbecility, attention, and various mental functions. One might say, quite correctly, that the "li" test belongs to the field visual acuity testing, and that therefore, it contains nothing new when used for measuring eye-fatigue. But as Dr. Ferree *has used* the test, it is new, in that it has brought into the visual acuity method a time element, just as we have brought into the rate-of-reading method the variation in illumination.

We hope that we shall not be troubled by imbecility, but if, by chance, there should be an imbecile among the graduate students and seniors whom we propose to use, we shall not feel worried for we think the method could not be applied to such a one as well as to any other.

The method is not offered as a substitute for the "li" method of testing eye fatigue. It possibly cannot lay claim to testing the same factors in eye fatigue as are tested by other methods. But tests so far made seem to indicate that the effect on the rate of reading, for example, by "switching on" a lamp in the field of view is greater when the eye is fatigued than when fresh, par-

ticularly when one is working at the "knee" of one's curve. Further, the location of the "knee" seems to be, for any given observer, a function of the condition of the eye. It is of course obvious that the maximum rate at which the observer reads, when there is sufficient illumination, must, as Dr. Ferree says, vary with a number of conditions, even for any given observer. By observing the change of shape and position of the curve, rather than its absolute location, for any observer, and the influence of various disturbing factors, we hope to be able to study some of the phenomena of eye fatigue.

TABLE I.

Angle	Time to read selection (seconds)	Mean (seconds)	Rate of reading $\left(\frac{1}{T} \times 1{,}000\right)$
—90	35.0	35.2	28.4
	37.7		
	33.0		
	35.0		
—60	35.0	36.0	27.8
	36.4		
	36.6		
	36.0		
—30	37.7	36.3	27.6
	36.2		
	35.8		
	35.5		
0	37.3	37.5	26.7
	39.4		
	37.2		
	36.2		
+30	37.8	36.7	27.3
	36.7		
	36.2		
	36.1		
+60	36.8	36.1	27.7
	35.3		
	36.2		
	35.9		
+90	35.0	35.7	28.0
	36.9		
	33.8		
	37.0		

However, attention should again be directed to the fact that no specific applicatiton is claimed for the method. We are simply dealing with a specific kind of eye measurement, reproducible within reasonable limits and capable of a fair degree of precision. The measurements, moreover, are seemingly dependent, in a definite way, on certain characteristics of the illumination used. But as to whether the method shall be used for testing eye fatigue or other ocular phenomena depending on illumination, we are not at present prepared to state.

As to the precision available, it may suffice to state that in Figs. 1 and 3, each point is the result of a single observation. Table I gives the data for Fig. 4. Four observations were made at each point: (The sequence in which observations were taken was so chosen as to minimize the influence of one observation on the next following).

REPORT OF THE COUNCIL FOR THE YEAR ENDING SEPTEMBER 20, 1915.*

Summary: Probably the most remarkable feature of the society's record for the fiscal year ended September 30, 1915, is the unusual amount and character of the work done by our committees. In fact the measure of success attained depends largely upon the work they accomplished. Among the special achievements the "Code of Lighting for Factories, Mills and Other Work Places" prepared jointly by the Committees on Factory Lighting and Lighting Legislation, and the thirteen technical reports by the Committee on Glare deserve particular attention. Financially, the society about held its own, only a small deficit being incurred; numerically, it suffered a slight loss, notwithstanding a substantial accession of new members. Both losses are readily accounted for by the generally adverse conditions prevailing in the business world during the earlier part of the year. But there was no apparent lessening of interest in affairs of the society, for the many meetings during the year were altogether as well attended as those of the preceding period. Beginning about the middle of the year there developed in the lighting world a condition manifestly favorable to the science of illumination: Certain industries experienced an enormous influx of business which has necessitated night work and a greatly increased use of artificial light. No doubt it has also emphasized the need of proper lighting, or perhaps the inadequacy of poor illumination, and effected many improvements in lighting practise. Closer relations with a number of societies in this country were promoted through joint meetings and the cooperation of committees. Foreign relations, of course, have improved but very little on account of the continuance of hostilities in Europe. In the following paragraphs an attempt has been made to give a general outline of the year's record.

I—FINANCE.

A report by Messrs. Wm. J. Struss & Company, certified public accountants, covering an examination of the accounts for the year is given in Appendix No. 1. Exhibit B shows that there was incurred on the year's operations a deficit of $278.89, approximately 2 per cent. of the total expenses. Columns have been added to this statement to show the relative sizes of the sources of income and expense for the past two years. Between the compared items only small differences are noticeable. The earnings were slightly higher than those of the preceding year, while the expenses were a little lower.

The surplus as of September 30, 1915 ($1213.19) is rather

* An abstract of this report was read at the annual meeting of the Illuminating Engineering Society held in New York, October 14, 1915.

small but not alarming. It must be remembered that the society differs from a commercial organization in that it is not run for the purpose of accumulating a large surplus.

Last year it was found expedient to increase the revenue by an accession of sustaining members. This year a further increase was provided for by the addition of a new grade of individual members through an amendment to the Constitution. It is hoped that the additional income from these two sources will at least care for the natural increases in expenses in the near future resulting from a broader and more substantial scale of activities.

II—MEMBERSHIP.

Following is a table which shows the changes in the membership. The defections were unusually large for two reasons: first, because the total membership at the beginning of the year included 135 members who in accordance with the required procedure of the Constitution should have been dropped for non-payment of dues; secondly, on account of the decidedly adverse and uncertain business conditions prevailing in the earlier part of the year. Taking into consideration the latter figure, the number of defections for the year was not abnormal. Moreover the net decrease is more or less characteristic of the numerical losses suffered by practically all societies like our own.

MEMBERSHIP CHANGES.

		Individual	Sustaining
Members October 1, 1914		1,472	35
Applications	151		12
Reinstatements	10		
Total additions	161		
Resignations and delinquents	220		1
Number which should have been dropped in the preceding year	135		
Deceased	7		
Total defections	362		
Net loss or gain in membership during the year		201	11
		1,271	46

Although the new members were drawn from many lines of professional and commercial endeavor, the classification of mem-

bers given in the last annual report remains practically the same. Quite the most part of the membership is identified with lighting and manufacturing companies. Neither was the geographical distribution of members changed materially. There appears to be a number of definite centers of activity such as New York, Chicago, Philadelphia, etc. From outside the vicinities of these cities the number of new applications has been comparatively small.

Through death the following members were lost: James C. Brooks, M. K. Eyre, James P. Malia, George Maurice, J. H. Parker, Joseph E. Putnam, F. C. Slade, Edgar S. Strunk.

At the annual election held last spring several constitutional amendments were adopted providing for a grading of all individual members into two classes—Associate Members and Members. Under the changes effected all the individual members of the society, except the officers and the Board of Examiners, passed into the grade of Associate Member. Those desiring admission to the grade of Member were required to file an application for transfer.

Up to the close of the year 134 of a total of 1271 members had been transferred to the grade of Member. The present indications, however, are that at least as many more will be transferred in the course of a month or two.

III—SECTIONS.

A summary of the activities of the several sections is given in the following table. While there was a loss of membership in all the sections, for reasons already given, a gratifying average attendance at all the meetings has been maintained. Also the number of acceptable papers contributed to the TRANSACTIONS exceeded that of the preceding year by two.

	No. meetings held	Average attendance	No. papers contributed to transactions	Membership at end of year
Chicago	9	54	3	201
New England	4	65	2	96
New York	9	147	7	402
Philadelphia	10	77	5	324
Pittsburgh	6	101	4	129
General	—	—	—	119
				1,271

IV—LOCAL REPRESENTATIVES.

The secretaries in those cities not having sections have been instrumental in promoting local interest in the work of the society; in several instances they gave valuable assistance to the Membership Committee in its campaign for new members. There are to be appointed shortly local secretaries in other large cities, particularly in the West and South.

V—COMMITTEES.

Twenty-one regular and special committees performed a vast amount of praiseworthy work, which constitutes a distinct service both to the society and the objects it aims to promote. Quite the most part of this work, let it be added, was accomplished only through many sacrifices on the part of the members of the committees. The detailed reports on all the committee activities might easily fill a fair sized volume. But since the purpose of the present report is to give merely an outline of the year's record, only summaries are given in the following paragraphs.

Progress.—Practically all the important technical and abstract journals were scrutinized as they appeared throughout the year for articles describing progress in illuminating engineering. Abstracts and the titles of such articles were entered on cards which were arranged under suitable headings. Letters were also addressed to the engineers in charge of lighting in the principal cities asking about developments during the year. Information was sought from the manufacturers of various light sources and auxiliaries. From all the data thus gathered a report was drafted, and later discussed and revised at a special meeting of the committee. Subsequently the report, which constitutes an excellent record of progress in the field of lighting, was published in the Transactions, Volume X, pp. 786-834.

Membership.—Despite the unfavorable business conditions, a campaign for new members was undertaken toward the middle of the year. Approximately one thousand names of prospective members were obtained from various sources, but principally from the members of the society. To each prospective member there was sent a neatly printed pamphlet on the work and objects of the society, which was prepared under the direction of the committee, together with a formal invitation to make

application for membership. This plan was supplemented by similar efforts on the part of several local committees, particularly in Baltimore and Philadelphia. As a direct result of this combined effort there was an accession of 155 new members. Under more favorable circumstances the results would undoubtedly have been much larger. Aside from this gain in numbers, however, it goes without saying that the campaign itself gave the society and its work some excellent publicity.

Sustaining Membership.—At the beginning of the year the committee was asked to increase materially the number of sustaining members and thereby provide sufficient additional funds to avert an anticipated deficit for the year. Eleven new members, whose annual dues aggregate $515.00 were obtained. Two members who had tendered their resignations were persuaded to retain their memberships. The committee followed the policy of presenting reasons for affiliation with the society to prospective applicants who were known to the members of the committee and who could therefore be approached on a somewhat personal basis. A list of 113 lighting and manufacturing companies was prepared and distributed among the members of the committee and others who could approach these companies with a reasonable chance of success. The outcome of the effort was as follows:

Applications received	11
Prospects who declined	12
Prospects deferred decision	3
Prospects failed to reply	23
Prospects not approached	64

Since submitting the foregoing report five of the companies whose names appeared on the list have made application for membership. Their annual dues total $110.

Revision of the Constitution.—After a careful consideration of many suggestions, the committee proposed several amendments, upon the adoption of which a second grade of individual members was created. When the amendments went into effect twenty days after the close of the annual election, all the members on record, except the officers and the Board of Examiners, passed into a grade of associate members. Provision was made, however, so that any associate member could be transferred to the grade of member before January 1, 1916, by merely sending

to the Council an application for transfer stating that under the requirements of the Constitution the applicant is eligible for admission to that grade. While the amendments, when first proposed, met with considerable opposition due somewhat to an imperfect understanding of the changes recommended, they were adopted at the election by a vote of more than six to one.

Convention.—The ninth annual convention which was held in Washington, D. C., was a pronounced success, thanks to the care with which all the arrangement details were handled by the committee. The program of thirty-eight papers and reports was the largest ever presented. The attendance, 310 members and guests, while somewhat lower than that of some previous years was very gratifying.

Advertising.—Although an effort was made to increase the amount of advertising in the TRANSACTIONS it was not attended by much success on account of the depressed condition of business in the first half of the year. The committee believes, however, that with a revival of better times a number of new advertisers will take space in the TRANSACTIONS.

Education.—An investigation was made of the status of instruction in good lighting in (*a*) schools of domestic science and economy (collegiate) in the leading educational institutions throughout the country, and (*b*) high schools in representative cities, by sending to suitable officers in such schools a questionnaire, with an accompanying explanatory letter asking for (1) the extent and character of such instruction and (2) suggestions for co-operation in extending such instruction. The large number of replies indicate that in the domestic science schools some instruction in good lighting is given. The amount varies from one to two lectures to one or two week's work. The work is given usually as part of a course in household sanitation or in connection with a course in house planning. Keen interest is expressed in the activities of the society in this direction. The work in these schools is being greatly handicapped by lack of suitable sources of informatiton. From the few replies received from superintendents of high schools it appears that only a comparatively small amount of attention is given to the subject of good lighting in these schools. Inquiries were also addressed to

men closely connected with the industrial interests to determine the demand for college graduates with a special training along the line of illuminating engineering. There is also under preparation by the committee a summary of the subject matter on good lighting as found in the text books on physics, hygiene, etc., in common use in secondary and high schools. A report on the above activities will be submitted later.

Reciprocal Relations With Other Societies.—Throughout the year the committee was in communication with twenty-nine societies believed to be interested in the propaganda of the society with a view to promoting co-operation in matters pertaining to illumination. These organizations included scientific, professional, educational, trade and commercial bodies. Several joint meetings were arranged for the discussion of lighting subjects. It is hardly necessary to add that the influence of the good work of this committee has been far reaching.

Popular Lectures.—For about two years this committee and a number of sub-committees have been preparing material for a series of six popular lectures on lighting. Definite outlines have been drafted by the Sub-committees on Industrial, Residence and Store Lighting; progress reports were submitted by the Sub-committees on Office Lighting and Elementary Lectures. The preparation of these lectures has been accompanied by many delays due to revisions and the desire on the part of the main committee to have the finished lectures in such form that they will make an appeal to the popular audiences for which they are being prepared. However, it is expected that one or two of the lectures will be available in the near future. With the material of these lectures ready for dissemination, the educational work of the society will be greatly augmented.

Exhibition Booth Committee (Gas).—Detailed descriptions, plans and photographs of miniature booths to present examples of good and bad lighting for exhibition by gas companies and associations were prepared and submitted to the American Gas Institute and the National Commercial Gas Association. The Institute published a description of the booths in its *Bulletin* and invited inquiries from interested parties. No responses were re-

ceived. While the booths have not been made, the plans and details are available for construction work at any time.

Exhibition Booth Committee (Electric).—Under the direction of the committee, six miniature interiors illustrating good and bad lighting practise were exhibited in several cities by lighting companies and before several association meetings. In every instance the booths were viewed by large crowds which manifested keen interest in the illumination effects produced.

Factory Lighting.—The work of this committee during the past year consisted of the formulation of a new code of lighting for factories, mills and other work places. Throughout this time the activities of the committee have been conducted in co-operation with the Committee on Lighting Legislation. A new Code of lighting was drafted, revised in accordance with the comments of the Committee on Lighting Legislation, electrical and safety departments of representative manufacturing organizations, and in its final form presented at the annual convention. Later it was published in the TRANSACTIONS, and then issued in pamphlet form for distribution to those interested in laws and regulations pertaining to factory and mill lighting. Requests for copies received from all parts of the country and abroad indicate the enthusiastic favor with which the Code has been received.

Lighting Legislation.—During the early part of the year the Committee on Lighting Legislation made a general survey of the state laws relating to lighting in the United States and prepared a transcript (taken from the statute book) of the laws relating to lighting in the States of New York, Pennsylvania, Connecticut, Illinois and Wisconsin. The study of these laws led to the conclusion that with few exceptions the existing state lighting legislation is crude, fragmentary and often meaningless. It was suggested that this committee frame a model lighting law to serve as a guide to legislators contemplating the enactment or amendment of laws pertaining to lighting. The difficulties in the way of framing a model law applicable to all classes of lighting being apparent, the committee decided to confine its work for a time to formulating a code of lighting for factories, mills and other work places and a code of lighting for school houses.

Accordingly a special Committee on Factory Lighting and a special Committee on School Lighting each submitted to the Committee on Lighting Legislation technical data and rules upon which to base a lighting code. A large part of the attention of the Committee on Lighting Legislation was devoted during the past six months to the consideration of drafts of the Code on factory lighting.

School Lighting.—Throughout the year the Committee on School Lighting endeavored to interest school and municipal authorities in lighting schools. A lecture on "Safeguarding the Eyesight of School Children," by the chairman of the committee, was given in several cities by members of the committee and others. Slides of the illustrations in the lecture have been made available for loan to those desiring to give talks on the subject. A special effort was made to promote co-operative relations with school associations, engineers and architects. In various trade and school journals publicity was given to the functions and work of the committee. A draft of a code of school lighting was prepared and submitted to the Committee on Lighting Legislation. A final draft will probably be available for publication in the near future.

Editing and Publication.—The committee supervised the editing and printing of all the publications of the Society. A small pamphlet setting forth the requirements and style of papers and discussions was prepared and distributed among the contributors of papers and discussions. The nine issues of the TRANSACTIONS were somewhat larger than those of the preceding year. All the numbers, save one, were published at intervals of forty days according to the regular schedule. The volume of publication work handled was very much larger than that of any previous year, due not only to the increased size of the the TRANSACTIONS, but to the greater number of papers printed in the advance form, the demand for reprints, copies of photographs, cuts, etc. The publication work is constantly assuming larger proportions and becoming more costly.

Papers.—The work of the committee has consisted of (1) accepting papers, reports and discussions for the TRANSACTIONS.

(2) securing and accepting papers for the convention; (3) obtaining and accepting papers for general and outside meetings in co-operation with the Committee on Reciprocal Relations. An effort was also made to obtain abstracts of all papers presented at meetings of the society but which for one reason or another were not available for publication in the TRANSACTIONS. For the convention there were received about fifty-five papers, almost twice as many as could possibly be accepted. This larger offering enabled the committee to select a program which included a nice diversity and balance of subjects. The success of the program was indicated by the lively and interesting discussions which the papers called forth. Of the sixty papers presented at section meetings twenty-four were accepted for publication. It is believed that a number of the remaining papers would have been accepted had the manuscripts been submitted.

Glare.—This committee has been occupied chiefly with the determination and formulation of the fundamental principles of glare and related conditions of lighting. These have been embodied in a general report. Considerable laboratory work was done on the optical properties of diffusing media and the results embodied in two general reports on instruments and methods and the theory and photometry of partial diffusion and in a series of special reports on print papers and inks, photographic papers, window envelopes, interior furnishings, projection screens and diffusing glassware. Other reports were prepared on the effects of glare on vision and on the suppression of the glare from automobile headlights. Finally, two reports dealing with engineering problems in avoiding glare in interior and street illumination were completed. The report on window envelopes was prepared at the request of the National Letter Carriers' Association, that on automobile headlights at the request of the American Society of Automobile Engineers. The Committee has also investigated retinal sensibility and adaptation to obtain some of the data urgently required to advance our knowledge of glare and of proper lighting conditions. A number of the foregoing reports have been published on the TRANSACTIONS; the others will appear later.

Illumination of Test-Types.—This committee is a joint committee appointed by the I. E. S. and the American Ophtholmolo-

gical Society and has for its objects the standardization of the illumination of the test-types and the methods of perimetry used in ophthalmologic practise. Typewritten copies of a report by the committee on the foregoing subjects were made available for distribution.

Nomenclature and Standards.—This committee held several meetings and devoted much of its attention to nomenclature. In its annual report, which appeared in the No. 8 issue of the 1915 TRANSACTIONS, is given a revised statement of the definitions of nomenclature and standards. The lambert as a unit of brightness was there proposed probably for the first time. Concerning the rating of lamps the committee proposed the following resolution which was later approved by the Council:

Resolved, That it is the opinion of this Committee: (*a*) that the output of all illuminants should be expressed in lumens; (*b*) that illuminants should be rated upon a lumen basis instead of a candlepower basis; (*c*) that the specific output of electric lamps should be stated in lumens per watt and the specific output of illuminants dependent upon combustion should be stated in lumens per B. t. u. per hour.

Research.—"The Research Committee last year made a general survey of fields needing investigation, and as a continuation of that work this year's commitee was formed with the expectation of arranging for actual experimental work on some of the problems discussed. The particular problem chosen was that of methods of comparing lights of different colors. It was commonly agreed that the criterion of equal brightness should be the basis of comparison of lights, but in the case of lights of different colors the application of this criterion is beset with great difficulties, the most important of which may be summarized as (1) erratic variation of judgment of individual observers, (2) systematic differences between observers and (3) variations of relative values of lights with change of illumination. The last two difficulties are not peculiar to comparisons by the method of equal brightness, but are due to inherent characteristics of the eye. It must therefore be recognized that in a very real sense there is no one definite ratio between the visual intensities of two lights of different color.

"The second and third difficulties are, however, systematic, and definiteness of results can be obtained by comparing lights at a standard illumination, using enough observers to average out the effects of difference between individuals, provided a method of measurement is available which will give reasonably precise value for the individual.

"The flicker photometer has given promise of furnishing such a method, and a complete scheme for the choice of observers and conditions in the use of this instrument has been proposed by Dr. H. E. Ives. The experimental work of the committee has been in general a test of the practicability of these proposals.

"The work has been done at the Bureau of Standards by two members of the Committee and details will be published in the *Bulletin* of the Bureau. The amount of data accumulated is indicated by the fact that the number of individual photometer settings made is about 60,000, besides preliminary work and incidental calibrations.

"The more important measurements made were as follows:

(1) On Ives' solutions for selection of observers, settings with the flicker photometer by 115 observers, a number of whom have repeated many times.

(2) On a blue glass representing the color difference between carbon and vacuum tungsten lamps, settings by 115 observers with the flicker photometer and with two forms of the Lummer-Brodhun photometer.

(3) On lamps of pentane standard color, and on solutions representing the color of high-efficiency tungsten lamps, settings by selected groups of observers on two photometers.

"The results cannot at present be discussed at length, but it may be said that certain parts of the methods under test are of indisputable value whether or not the system of measurements be adopted as a whole, and so far as time is available the investigation will be continued at the Bureau with a view to making use of those methods for measurements in which their use may be justified."

Other Committees.—Deserving of particular mention is the work of several committees whose activities, while they are more

or less regular from year to year, play an important part in the effective conduct of the society's affairs. Such committees are: the Finance Committee who audited all the treasury disbursements and submitted monthly financial reports; the Committee on Tellers who counted and reported the vote of the annual election, a task which involved considerable detail; the Committee on Section Development who encouraged closer co-operation among sections through the exchange of ideas on section administration; and the Board of Examiners who passed upon applications for admission to the society from applicants residing without the jurisdiction of the several sections.

VI—TRANSACTIONS.

During the year the size of the published TRANSACTIONS continued to increase. The number of pages exclusive of the news section, totaled 1015 as against 944 pages for the same previous period. The papers and discussions covered a wide range of illuminating engineering subjects. Considerable emphasis was laid upon the physiological aspects of lighting questions, and a large number of pages were devoted to practical problems and their solutions.

A comparison of the papers in the TRANSACTIONS for the last three years, classified according to subjects, shows but little variation in distribution. Classified according to the numbers of pages, however, there is a noticeable difference owing, as noted above, to certain phases and problems assuming apparently greater importance over others. The evident conclusion to be drawn from the regularity of the distribution is that illuminating engineering is now developing along more or less definite lines.

The increasing size of the TRANSACTIONS will probably necessitate dividing next year's issues into two volumes.

VII—GENERAL OFFICE.

There has been a marked increase in the volume of business handled in general office due to the following causes: (1) The performance of work hitherto cared for entirely by committees; (2) growth of the society's publishing business; (3) various requests for information on society affairs and the literature of

illuminating engineering. Frequently the office force has been greatly overtaxed and required to put in considerable overtime. Further increase in the business, which is to be expected, may require the employment of a third assistant or clerk, if the work entrusted to the office is to be handled with the required efficiency and dispatch.

VIII—GENERAL.

It may not be inappropriate to mention briefly several facts which, while they are more or less incidental to society affairs, appear to have a bearing on illuminating engineering.

Both the National Electric Light Association and the National Commercial Gas Association have issued educational courses for salesmen and other representatives of lighting companies. A large part of each course is devoted to illumination. It is hardly necessary to say that such instruction is bound to exert a beneficial effect upon lighting practise, particularly in the case of small lighting installations.

Certain industries in this country have within the past year experienced an abnormal influx of business necessitating enlargements and additions to manufacturing plants and the working of large forces at night. However sinister this condition may be, it has greatly increased the demand for artificial light and no doubt emphasized more than ever the importance of good illumination, or perhaps the disadvantages of poor lighting. A continuance of such circumstances should facilitate many needed improvements in the design of lighting installations.

The spreading of the so-called preparedness propaganda will no doubt witness the development of many new and interesting applications of light.

Our relations with foreign societies have been practically suspended pending a cessation of hostilities in Europe.

APPENDIX.

WM. J. STRUSS & CO.

CERTIFIED PUBLIC ACCOUNTANTS.

93-99 NASSAU ST.

NEW YORK.

October 29, 1915.

MR. A. HERTZ,
Chairman, Finance Committee,
Illuminating Engineering Society,
New York, N. Y.

DEAR SIR:

In accordance with your instructions we have examined the books and accounts of the Illuminating Engineering Society for the twelve (12) months ended September 30, 1915.

The results of this examination are set forth in the two exhibits, attached hereto, as follows:

Exhibit "A"—Balance Sheet, September 30, 1915.

Exhibit "B"—Earnings and Expenses, for the twelve months ended September 30, 1915.

The cash over draft as shown on the Balance Sheet ($581.89) is occasioned by the drawing of checks for certain outstanding debts of the Society. Sufficient of these checks were held to protect an "actual overdraft."

We hereby certify that the accompanying Balance Sheet is a true exhibit of its financial condition as of September 30, 1915, and that the attached statement of Earnings and Expenses is correct.

Respectfully submitted,

(Signed) WM. J. STRUSS & COMPANY,
Certified Public Accountants.

BALANCE SHEET—SEPTEMBER 30, 1915.

EXHIBIT "A."

ASSETS.

Cash on hand		$ 100.00
Accounts Receivable:		
Dues sustaining members	$ 70.00	
Current fees	32.50	
Advertising	50.57	
Transactions	15.45	
Reprint	29.95	
Primer	6.10	204.57
Investment:		
Northern Pacific and Great Northern Railway Bonds, due 1921, $2,000.00 book value		1,920.00
Inventories:		
Transactions	$ 30.00	
Primer	65.00	
Badges	7.00	102.00
Electric exhibition booth		289.25
Furniture and fixtures		674.73
Prepaid charges		108.84
		$3,399.39

LIABILITIES.

Cash—Overdraft	$ 581.89	
Accounts payable—Current	965.78	
Accounts payable—Unpresented items	491.33	
Advance fees	2.50	
Advance dues	144.70	$2,186.20
Surplus Account—Balance October 1, 1914	$1,401.01	
Miscellaneous adjustments	91.07	
	$1,492.08	
Net loss for the twelve months ended September 30, 1915, as per Exhibit "B"	278.89	$1,213.19

STATEMENT OF EARNINGS AND EXPENSES.

EXHIBIT "B."

EARNINGS.

	1914-1915		1913-1914	
	Amount	Per cent.	Amount	Per cent.
Members dues	$ 6,425.00	52.34	$ 7,069.75	57.87
Sustaining dues	3,240.00	26.39	2,790.00	22.83
Initiation fees	375.00	3.05	340.00	2.78
Advertising	1,343.19	10.94	1,407.12	11.51
Transactions—Sales	715.18	5.83	420.93	3.44
Reprint sales	.81	0.00	16.55	0.14
Primer sales	23.59	0.19	70.45	0.58
Badge sales	.50	0.00	9.00	0.08
Certificates sales	.60	0.00	5.05	0.04
Miscellaneous	48.09	0.39	11.00	0.09
Interest earned	104.20	0.86	78.24	0.64
Total	$12,276.16		$12,218.09	

EXPENSES.

	1914-1915		1913-1914	
	Amount	Per cent.	Amount	Per cent.
Transactions	$3,836.13	30.55	$3,873.68	31.01
General Office	5,305.84	42.26	5,139.17	40.02
New York Section	420.62	3.35	357.71	2.78
Philadelphia Section	309.98	2.47	211.68	1.64
Chicago Section	282.05	2.24	289.95	2.25
Pittsburgh Section	228.87	1.82	296.72	2.31
New England Section	113.78	0.91	66.92	0.52
Committee expenses	399.17	3.18	711.57	5.54
Committee on Education	81.60	0.65	0.00	0.00
Election expenses	144.34	1.15	83.13	0.64
Miscellaneous expenses	225.33	1.80	277.97	2.17
Exchanges and discount	27.38	0.22	24.82	0.02
Conventions	1,105.00	8.80	1,386.85	10.80
Depreciation of furniture and fixtures	74.96	0.60	120.84	0.94
Total	$12,555.05		$12,841.01	
Excess of expenses over earnings	$278.89		$622.92	

DISCUSSION OF PAPER ENTITLED "THE RETINAL SENSIBILITIES RELATED TO ILLUMINATING ENGINEERING."

(*Continued from page 21.*)

DR. C. E. FERREE: In discussing Dr. Nutting's interesting paper I wish first to offer an explanation of the results which he considers so paradoxical in his experiments on the effects of local adaptation. Beginning with a pre-exposure field of 0.1 ml. in brightness he finds contrary to his expectations that as the size of the illuminated field is decreased and that of the black surrounding field is increased, the instantaneous threshold is raised instead of lowered. He says: "The remarkable result was obtained that as the field was stopped down with black, the threshold was *raised, i. e.,* the sensibility *decreased* whereas one might expect the lowering of the average illumination to increase sensibility. . . . The effect of introducing a black spot in the center of a light field was to *increase* sensibility in every case, at 100 ml. a large black spot doubled the sensibility." This effect on sensibility lines up with a phenomenon first described by Purkinje in 1825 and later discussed and investigated by Brücke in 1851, by Aubert in 1862, by Hering in 1878, by Ebbinghaus in 1902, and by the present writer in 1912. This phenomenon may perhaps best be characterized as an after-effect of physiological induction. When the pre-exposure field is surrounded by a black field, it is made subjectively lighter by physiological induction. As the ratio of size of dark surrounding field to light field gets larger this effect is increased, becoming quite great when the light field is small. This physiological induction is just as capable of giving an after-effect as if it were objectively aroused. That is, the result of the pre-exposure to the light field is a dark after-effect, commonly called after-image, which increases in strength as the ratio of the size of the dark surrounding field to the light field is increased. This dark after-effect tends to suppress the response of the eye to the succeeding stimulation by the test field and to raise the threshold as Dr. Nutting has found. It is quite obvious that the opposite effect would be produced when the surrounding field was light and what served as the pre-exposure

for the test field was dark. The subjective effect of this dark area would be enhanced by physiological induction for the light surroundings and the white after-effect would be correspondingly increased, which would add to the effect of the succeeding stimulation by the test field and lower the threshold of vision or increase the sensitivity. I am glad to see this phenomenon so definitely connected with effect on the sensitivity of the eye as has been done by Dr. Nutting. In my paper before this present Convention in discussing the effect of pre-exposure on the sensitivity of the eye, I have stated that in the pre-exposure the brightness of the surrounding field as well as what serves as the direct pre-exposure for the test field must be taken into account. This is made all the more necessary because of the rapid adaptation effects in the paracentral and peripheral parts of the retina.

In agreement with Dr. Nutting's broad treatment of the responses of the retina, I want particularly to emphasize that it is not enough to investigate acuity and brightness and color discrimination if a comprehensive knowledge of the functional state of the retina is desired. In pursuance of this thought I have for the past two years been investigating the effect of different conditions of lighting on the retina in four regards: (1) the effect on acuity and on sensitivity to brightness and color; (2) the effect on the lag of sensation or the time required for the retina to give its full response; (3) the effect on the rate of exhaustion; and (4) the effect on rate of recovery. Short of this a complete account cannot be given of the functional state of the retina at any time or as the result of any condition or set of conditions to which it may be subjected.

DR. C. E. FERREE (Communicated): Dr. Nutting is quite right in pointing out that the constant of visibility is not obtained by determining the relation of the lumen to the watt. The lumen is not a sensation magnitude, therefore its ratio to the watt does not correlate sensation with the stimulus which arouses it. The ratio obtained is no more than a reduction factor between two physical units. In determining the lumen the eye is used merely to equate two physical magnitudes and nowhere in the process is more than a relative value put upon sensation. Closely connected with this point is the question to which Dr. Nutting devotes considerable

space in this and a related paper,[1] namely, whether sensation can be measured in terms of the stimulus. If it can be so measured the converse is, of course, true that the stimulus can be measured in terms of sensation; that is, the eye can with the proper calibration be used directly as a radiometric instrument. Dr. Nutting seems inclined to hold out hope that this measurement can be made and gives formulae which purport to express the relation between sensation and its stimulus. In order that such a position may be maintained at least three conditions must be fulfilled. (1) It must be assumed that all just noticeable differences occurring anywhere in an intensity series are equal as sensation quantities. That is, measurement is not possible unless a numerical scale can be applied and it is obviously impossible to apply a numerical scale unless sensation can be laid off in equal divisions. There is absolutely no way of proving that all just noticeable differences in sensation estimated as sensation quantities are equal. If they are accepted as equal it must be done solely on the grounds of logical self-evidence. Many psychologists are unwilling to grant their equality on these grounds. (2) It must be shown that it is possible to assign a finite value to the Fechner fraction at the threshold of sensation. This cannot be done, as Dr. Nutting has pointed out, in accord with the conventional method of computing the Fechner fraction. (3) A way must be found for computing the deviations of the Fechner fraction from constancy. While Dr. Nutting has made the most interesting attempt I have yet seen to determine constants which will represent these deviations in different parts of the scale, I am inclined to think that he would not himself consider the results attained as much more than an interesting and suggestive approximation. In this connection I must also take issue with Dr. Nutting's statement that the Fechner formula "has been accepted by psychologists for half a century."[2] The thesis that sensation can be measured was propounded in 1852, but since that time the literature of psycho-physics has been strongly against it. In fact the measurement of sensation can hardly be considered a problem of modern psycho-physics. The measurement of sensitivity alone is considered as feasible. While I recognize that it is only natural

[1] *Bulletin* of the Bureau of Standards, 1908-1909, V, pp. 261-309.

[2] *Op. cit.*, p. 292.

for the physicist to attempt to do it, I cannot, considering the present inadequacy of our knowledge, express too strongly here my distrust of all attempts to represent mathematically the characteristics of the response of a sense organ; to forecast by mathematical computations or formulae what will happen in a given situation; or to interpolate values in an experimental series. Physiological optics, so far as the responses of the retina are concerned, is and must remain for some time, I fear, essentially and solely an experimental subject.

Such further comments as I have to make on Dr. Nutting's paper may be summed up briefly as follows. (1) In the work on the recovery of the retina, no statement is made of what intensity of light the eye was exposed to and how long it was exposed before entering the dark room. Recovery curves do not have very definite meaning when one is left in ignorance of these points. Furthermore, the rate of recovery was damped because of the method used in determining the rise of sensitivity. The observer's eye was exposed to the test surface all of the time and sensation was kept just above the threshold by moving the absorption wedge from apex to base across the beam of light at the rate that was needed to give the just supraliminal sensation. That is, the rate of recovery was retarded by the fact that the eye was exposed to light all the time during the recovery period, and this light, moreover, was being increased in proportion as the thinner portions of the wedge were brought into the path of the light. Less damping would have resulted from the use either of Nagel's method, or of its alternative,—the determination of the threshold at fixed intervals during the stay in the dark room, between which determinations the eye is exposed to no light. In our own work the latter method is always employed. (2) The work on local adaptation also would have had a more definite meaning and value if the time during which the eye was allowed to adapt were given; for adaptation is a function of time as well as intensity and area of the test field. (3) Under purity sensibility the change which Dr. Nutting calls change of purity is usually spoken of in physiological optics as change of saturation. That is, he has produced just noticeable changes in the proportion of colored to colorless component of the sensation. A more customary procedure in determining purity sensibility would have

been to have started with a given range of wave-lengths and have found out how much of another given small range of wave-lengths, homogeneous for sensation, must be added to produce a noticeable change in the quality of sensation. The chief difference between this series of determinations and those represented by what Dr. Nutting has called determinations of hue sensibility is that wave-lengths would have been combined from any or all parts of the spectrum instead of taking only those which are contiguous in the spectrum. It seems surprising to me that in combining the colors of the spectrum with white light the number of just noticeable changes in sensation from full color to no color should have been approximately the same for all of the colors, because (*a*) the colors differ so in saturation, and (*b*) we have never found it to be so in our own determinations of a similar kind. (4) The heading "Rate of Decrease of Sensibility," page 10, I judge to be a misprint for the work treated of under it refers to the rate of increase of sensation with increase of exposure for short exposures. Moreover, the next topic "Local Adaptation" in effect treats of rate of decrease of sensibility with increase of time of exposure. Since in this latter topic it is shown that after a maximum is reached sensibility decreases with increase of exposure, the decrease continuing for many minutes, one cannot help but wonder that exception is not taken to Broca and Sulzer's statement that the permanent level of sensation is reached in a fraction of a second after the maximum is attained, or even in one to two seconds, as is more conservatively stated in other places in their articles. Broca and Sulzer, it may be noted, not only assume that sensation reaches a permanent level in a very short interval after the maximum is attained, but they make the assumption a crucial point in the formulation of their method of determining lag. In this regard their work is open to rather serious criticism. It seems to me further in this connection that the work of Blondel and Rey for intensities near the threshold of sensation could have been done more feasibly and directly by methods of determining lag, provided of course that methods had been used which could be shown to have logical sureness. (5) In Dr. Nutting's method of determining the breadth of the pupil, it would seem to me that the pupil is in the shadow while the determination is being made, and, therefore, is not reacting to

the intensity of light used. I will qualify this opinion, however, by the statement that I do not fully understand just how the determination is made and how the intensity of light falling on the pupil at the time the determination is made is measured. A clearer statement of procedure would not, I think, have been out of place here.

In closing I wish to say that it is gratifying to see an article in these columns in which so thorough and so systematic an insight is shown into the functional activities and interactions of the retina. It is amazing sometimes to see the use that is made of the eye as a recording instrument where so little knowledge is shown of its characteristics and of the technique that is needed for its control. As a syllabus which outlines and correlates some of the most essential characteristics of the retina's response to its stimulus, the article is unusually worthy of the study of every member of the society. With proper attention to these characteristics, there is every reason to believe that the eye, which is the most sensitive of the instruments used in the measurement of light, may become also an instrument of precision; for it is found to be erratic in its responses chiefly (*a*) because of its great sensitivity, and (*b*) because of a lack of knowledge of control of the factors which influence these responses. In fact work has already been carried far enough to show that the above prediction is not over-optimistic with regard to many of the uses to which the eye may be put. It has, it must be admitted, peculiarities of response not belonging to other instruments sensitive to radiation, but if these are thoroughly known, it is possible to use it in such a way as to introduce a minimum of error. In any event the eye cannot be eliminated from scientific work. It is and will remain in some type of use the ultimate recording instrument in the employment of most of our physical instruments; for if in case of the use of the most of these instruments the final link between meaning and the physical event is not in terms of judgment of color and brightness, it is in terms of a judgment of space. For this reason a systematic study of the eye as a recording instrument can no more be consistently left out of the program of the physical scientist than that of any of the other instruments upon which his knowledge of the physical event depends.

TRANSACTIONS

OF THE

Illuminating Engineering Society

NO. 1, 1916

PART II

Miscellaneous Notes

Council Notes.

A meeting of the Council was held in the general offices of the society, 29 West 39th St., New York, N. Y., January 13, 1916. Those present were E. M. Alger, Louis Bell, C. O. Bond, W. A. Durgin, George A. Hoadley, Clarence L. Law, C. A. Littlefield, general secretary; M. Luckiesh, A. S. McAllister, L. B. Marks, treasurer; Preston S. Millar, J. L. Minick, J. A. Norcross. Messrs Louis Bell, E. P. Hyde and Norman Macdonald were present upon invitation.

The meeting was called to order at 3.00 p. m. by Vice-president George A. Hoadley, in the absence of President Steinmetz.

The minutes of the December meeting were adopted as printed.

Fourteen associate members were transferred to the grade of member.

Twelve resignations were accepted subject to informal reinstatement where resignations are withdrawn.

Upon recommendation of the Finance Committee payment of vouchers No. 2,350 to No. 2,379 inclusive and No. 2,383 aggregating $1,493.00 was authorized, subject to the approval of the general secretary.

The Finance Committee submitted an estimate of the income and expenses for the present year. (Estimated income, $14,181; expenses, $13,800.)

The following report was presented by the Council Executive Committee:

A meeting of the Council Executive Committee was held in the general offices of the Society, 29 West 39th Street, New York, December 31, 1915. The following business was transacted:

1—The approval of 89 applications for transfer to the grade of member.

2—The election of 6 associate members subject to the approval by the Board of Examiners.

3—The election of 1 member subject to the approval of the Board of Examiners.

Consideration was given to the question of providing a new transfer application blank. It was understood that the general secretary, Mr. C. A. Littlefield, would co-operate with the chairman of the Board of Examiners and draw up a tentative form to be submitted for the approval of the Council.

The report was adopted.

The following suggested changes in the By-Laws were submitted by the Board of Examiners, Dr. A. S. McAllister, chairman:

CHANGES IN THE BY-LAWS PROPOSED BY THE GENERAL BOARD OF EXAMINERS.

The words in italics indicate the proposed changes.

ARTICLE III.

(d) Section 4: The privileges attaching to membership in the Society shall not be accorded to newly-elected members until they have paid their entrance fee and current dues. This by-law shall be printed upon the *form used in notifying a candidate of his election*.

(e) Section 4: Upon receipt of an application for membership, which shall be made on the official form, the General Secretary, or the Secretary of a section, shall see if it has been properly filled out. If not, he shall return the form and notify the applicant of the deficiency. When an application is in proper form it shall be forwarded to the chairman of the *local* Board of Examiners. The Secretary of a section shall conduct for the Board of Examiners such correspondence with applicants and their referees as the Board may direct.

(f) Section 4: *Applications for membership received from persons not residing within the territory of any section shall be referred for recommendation to a General Board of Examiners consisting of three members appointed by the Council.*

(g) Section 4: *The General Board of Examiners shall collect such information concerning the eligibility of all applicants as may be necessary to make recommendations to the Council for final action. Each person endorsing an application for transfer or admission to the grade of Member and each person referred to by the applicant shall be requested by the General Secretary to fill out a prescribed confidential form for consideration by the General Board of Examiners.*

(h) Section 4: *No application for transfer or admission to the grade of Member shall be acted upon by the General Board of Examiners until replies have been received from the number of persons prescribed by the Constitution. In the event of failure to receive replies, or of receipt of unfavor-*

able replies, the General Secretary may call upon the applicant to furnish additional names.

(f) Section 3 (Reletter this clause (i) Section 4): Objection to the admission *or transfer* of a candidate must be accompanied by specific reasons for such objection.

ARTICLE VII.

(e) Section 8—(cancel this clause): The Council shall appoint a General Board of Examiners to pass upon applications for membership received from persons not residing within the territory of any section.

The Board of Examiners was instructed to proceed in accordance with the above-given proposals.

A report giving the program of the Mid-winter Convention was submitted by Mr. Clarence L. Law, secretary of the Mid-winter Convention Committee.

It was moved that a resolution, properly engrossed, be presented to Mr. Thomas A. Edison at the time of tendering him honorary membership.

Dr. E. P. Hyde, chairman of the Committee on Lectures, presented an oral report on the progress of his committee. In substance, the report was as follows:

While the course of lectures at Johns Hopkins University dealt with the fundamentals and the theoretical side of illuminating engineering and was more or less inspirational in its nature, it is proposed to make the course to be given this fall more practical, and have as a result volumes which are exhaustive on the subject of illuminating engineering. A brief outline of the tentative course is as follows: 1. General lectures giving a brief summary of the subjects covered by the last lectures, and the expansion on such subjects as have grown in the meantime. 2. Special lectures on (*a*) interior illumination, treating of the lighting of schools, factories, the home, theatres, hospitals, art museums, etc., and (*b*) exterior illumination, dealing with the lighting of buildings, streets, sign and pageant lighting, headlights, etc. It is also hoped to draw up codes giving practical and effective methods of using the foregoing lectures. The course on the whole is to be thoroughly practical and will be of material assistance in solving the various illuminating problems of the day. It is thought to be very desirable to hold the lectures at the University of Pennsylvania provided the whole university will co-operate to make the course a success.

Reports on section activities were submitted by Vice-presidents J. L. Minick (Pittsburgh), G. A. Hoadley (Philadelphia), Clarence L. Law (New York). Mr. Durgin reported on the Chicago Section activities for Mr. Vaughn, and Dr. Bell spoke of the program of the New England Section for Mr. C. A. B. Halvorson.

It was decided to issue a monthly bulletin to the membership giving the dates, speakers, etc., of the meetings to be held by the various sections, as well as miscellaneous notes of interest. This scheme is to be tried out until the end of June, 1916.

It was voted to refer to the Committee on By-Laws, to be appointed by Dr. Steinmetz, the question of adopting a by-law requiring all committee reports to be signed by all members of the committee.

A report regarding the publication of committee papers read by the general secretary was received from the Committee on Papers. It voted to refer a copy of this report to the Committee on By-laws.

Mr. M. Luckiesh, chairman of the Committee on School Lighting, reported that his committee was finishing a code which they hoped to submit to the

Committee on Lighting Legislation in the near future.

The following committee appointments were confirmed:

Committee on Education: F. K. Richtmyer, Chairman, reappointed.

Sub-committee (Popular Lectures) on Industrial Lighting: H. H. Magdsick, C. A. B. Halvorson.

Committee on Ways and Means (of Lecture Committee): J. D. Israel, A. S. McAllister, W. J. Serrill, G. H. Stickney.

Editing and Publication: A. S. McAllister.

It was voted to request suggestions from the Board of Examiners as to drafting of a new form of transfer application blank and the question of the amount of transfer fees. These suggestions are to be given to the Council and later made a part of the by-laws.

Section Meetings.

Chicago Section

January 13, 1916, in the Commonwealth Edison Building. Paper, "Exterior Lighting of Buildings," by J. R Cravath. Exhibits of flood lighting reflectors were presented by the National X-Ray Co., the General Electric Company, and the American Flood Lighting Company. Attendance 54.

February 10, 1916, in the Commonwealth Edison Building. Paper, "Factory Lighting" by Fred. Schwarze. Attendance 59.

February 28, 1916, at the rooms of the Western Society of Engineers, 1735 Monadnock Block, Chicago. Joint meeting of the Chicago Sections of A. I. E. E. and I. E. S. and the Electrical Section of the W. S. E. Papers: "Recent Street Lighting Problems and Developments" by J. R. Cravath; "Some Experiences and Tests in Connection with Chicago Street Lighting" by A. C. King; "Street Lighting Plans of Milwaukee" by F. A. Vaughn.

March 16—Latest Developments in Incandescent Lamps.

April 20—Relation of Illumination to Interior Architectural Effects.

June 15—Modern Reflectors and Shades for Gas and Electric Lighting.

The names of the authors of these papers will be announced later.

New England Section

January 13, 1916, at the Engineers' Club, 2 Commonwealth Avenue, Boston, Mass. Paper, "Floodlighting" by Dr. Louis Bell.

February 16, 1916, at the Lynn Classical High School, North Common St., Lynn, Mass. Afternoon: "Street Lighting Problems as Solved by Miniature Streets"; evening: joint meeting with Lynn Section of A. I. E. E. Mr. Walter D'Arcy Ryan, chief of illumination of the Panama-Pacific International Exposition, gave a lecture on the "Illumination of the Panama-Pacific International Exposition" which was illustrated by a selection of large colored transparencies.

April 13—Address by Dr. Charles P. Steinmetz, president of the Illuminating Engineering Society.

New York Section

January 13, 1916, in the Engineering Societies Building, 29 West 39th St. Papers: "Light Transmission in Telescopes" by Mr. F. L. G. Kollmorgen, of the Eastern Optical Company; "The Projection Lantern; Some of Its Uses, Abuses and Misconceptions," by J. B. Taylor. Attendance 65.

By motion of the Board, the February meeting was cancelled in favor of the mid-winter convention.

The following meetings and papers have been announced:

March 14—Joint meeting with American Society of Mechanical Engineers. Paper, "Application of the New Factory Code Lighting" by Prof. C. E. Clewell of the University of Pennsylvania.

April 6—A lecture by Dr. Charles P. Steinmetz on "Illuminating Engineering."

May 11—A paper by Mr. Bassett Jones entitled "Office Lighting."

June—A paper by Mr. Wm. Dempsey of the New York Edison Company, entitled "Street Lighting with Mazda C Lamps." This meeting is to be held outdoors and will include an inspection trip through the streets of New York.

Philadelphia Section

January 21, 1916, at the Engineers' Club, 1317 Spruce St., Philadelphia, Pa. Papers: "Lighting Legislation" by L. B. Marks; "The Work of the Lighting Service Department of the Philadelphia Electric Company," by G. Bertram Regar.

February 18, 1916, at the Engineers' Club, 1317 Spruce St., Philadelphia, Pa. Paper, "Tests on Street Illumination," by Preston S. Millar. This paper was accompanied by lantern slides, and a model of a section of a street lighted by electric lamps. Various measuring instruments were exhibited during the meeting. Attendance 55.

March 17—Joint meeting with the Philadelphia Section of the A. I. E. E. Paper, "Engineering Training as a Business Asset," by Charles F. Scott, Professor of Electrical Engineering, Sheffield Scientific School of Yale University.

April 21—"Type C Lamps in Street

Lighting," by T. J. Pace, Commercial Engineer, Westinghouse Electric & Manufacturing Company.

May 19—"Educational Aspects of Illumination," by Prof. F. K. Richtmyer, Chairman, Committee on Education, Illuminating Engineering Society.

June 16—"Artificial Lighting for a Hundred Years," by William J. Serrill, Engineer of Distribution, United Gas Improvement Company.

Pittsburgh Section

January 21, 1916, at the Engineers' Society Rooms, Oliver Building, Pittsburgh, Pa. Paper, "The Laws of Reflection and Transmission of Light," by Mr. T. W. Rolph, of the National Electric Lamp Association, Cleveland, Ohio.

February 18, 1916, at the Hof Brau, Cleveland, Ohio, joint meeting with A. I. E. E. Paper, "Daylight and Twilight Illumination," by Prof. H. H. Kimball, of the Department of Agriculture, Washington, D. C.

March 24—"Lighting of the Panama-Pacific International Exposition," by W. D'A. Ryan, Chief of Illumination, Panama-Pacific Exposition.

April 21—"Symposium on Interior Lighting."

New Members.

The following men were elected members at a Council meeting held February 11, 1916:

Allen, M. W.
Superintendent, National Carbon Co., Madison Ave. and W. 117th St., Cleveland, Ohio.

Myers, E. B.
Engineer, United Gas Improvement Co., 1401 Arch St., Philadelphia, Pa.

New Associate Members.

The following men were elected associate members at a meeting of the Council held February 11, 1916:

BRADY, N. F.
Vice-president, The New York Edison Co., 54 Wall St., New York, N. Y.

BULLER, C. S.
New Business Assistant to Division Agent, Public Service Electric Co., 118 Main St., Hackensack, N. J.

BURNETT, H. D.
Electrical Engineer, Canadian General Electric Co., 212 King St. West, Toronto, Canada.

CORBY, RALPH B.
Manager, National X-Ray Reflector Co., 21 W. 46th St., New York, N. Y.

FINK, COLIN G.
Chemist, General Electric Co., 5th and Sussex Sts., Harrison, N. J.

GARRATT, ALLAN V.
General Manager, The Lombard Governor Co., Ashland, Mass.

INSULL, SAMUEL
President, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

JARRETT, LE GRAND
Assistant in charge of Life Test and Precision Photometry, Westinghouse Lamp Co., Bloomfield, N. J.

JOHNSON, E. H.
Assistant Professor of Physics, Kenyon College, Gambier, Ohio.

MCCALL, JOSEPH B.
President, Philadelphia Electric Co., 1000 Chestnut St., Philadelphia, Pa.

PARKER, GEORGE SIMS
Assistant in Electrical Engineering, Columbia University, New York, N. Y.

STONE, J. P.
Electrical Engineer, New Jersey Zinc Co., Franklin Furnace, N. J.

Mr. Colin G. Fink, Chemist of the General Electric Company, Harrison, N. J., was elected an associate member at a meeting of the Council held January 13, 1916.

Transfers.

Eighty-nine applicants were transferred to the grade of member at a meeting of the Council Executive Committee held December 31, 1915:

ABELL, H. C.
Engineer, American Light & Traction Co., 40 Wall St., New York, N. Y.

ALLEN, WALTER C.
Electrical Engineer for the District of Columbia, District Building, Washington, D. C.

AMBLER, THOMAS M.
Manager, Commercial Department, Brooklyn Union Gas Company, 176 Remsen St., Brooklyn, N. Y.

ANDREWS, W. S.
Consulting Engineer, General Electric Co., Schenectady, N. Y.

ATKINS, DAVID FOWLER
Chief Engineer, Bureau of Gas and Electricity, Department of Water Supply, Gas and Electricity, Municipal Building, New York, N. Y.

BARNES, WILL W.
Sales Manager, Bayley & Sons, Inc., 101 Park Avenue, New York, N. Y.

BELL, LOUIS
Consulting Engineer, 120 Boylston St., Boston, Mass.

BESSON, WM. C.
Treasurer, The New York Mutual Gas Light Co., 36 Union Square, New York, N. Y.

BRADLEY, WM. H.
Chief Engineer, Consolidated Gas Co. of New York, 130 E. 15th St., New York, N. Y.

BROOKS, MORGAN
Professor of Electrical Engineering, University of Illinois, Urbana, Ill.

BROWN, H. E.
Installing Engineer, National X-Ray Reflector Co., 235 W. Jackson Blvd., Chicago, Ill.

CAMPBELL, JOHN
Superintendent of Special Service Department, The Edison Electric Illuminating Co. of Boston, 39 Boylston St., Boston, Mass.

CARY, WALTER
Vice-president and General Manager, Westinghouse Lamp Co., 1261 Broadway, New York, N. Y.

CHURCHILL, WILLIAM
Assistant Sales Manager, Corning Glass Works, Corning, N. Y.

CLARK, WALTON
Engineer, The United Gas Improvement Co., Broad and Arch Sts., Philadelphia, Pa.

CRESSMAN, RUSSELL B.
Gleason Tiebout Glass Co., 71 W. 23rd St., New York, N. Y.

CROUSE, J. ROBERT
Manager of Sales and Member of Advisory Board, National Lamp Works of General Electric Co., Nela Park, Cleveland, O.

DOANE, SAMUEL EVERETT
Chief Engineer, National Lamp Works of General Electric Co., Nela Park, Cleveland, O.

DONAHUE, E. J.
Engineer, Public Service Gas Co., St. Paul's and James Aves., Jersey City, N. J.

DONKIN, WILLIAM A.
General Agent, Duquesne Light Co., 435 Sixth Ave., Pittsburgh, Pa.

EDGAR, CHARLES LEAVITT
President and General Manager, Edison Electric Illuminating Co. of Boston, 70 State St., Boston, Mass.

EGLIN, WILLIAM C. L.
Second Vice-president and Chief Engineer, The Philadelphia Electric Co., 1000 Chestnut St., Philadelphia, Pa.

ELINGER, EDGAR
Secretary and Treasurer, L. K. Comstock & Co., 30 Church St., New York, N. Y.

ELY, ROBERT B.
Lighting Service Bureau, The Philadelphia Electric Co., 1000 Chestnut St., Philadelphia, Pa.

ERICKSON, FREDERICK W.
Chief Engineer, Lord Electric Co., 105 W. 40th St., New York, N. Y.

FOWLE, FRANK F.
Consulting Electrical Engineer and Receiver, Central Union Telephone Co., 212 W. Washington St., Chicago, Ill.

FREEMAN, C. K.
Secretary, Armspear Manufacturing Co., 447 W. 53rd St., New York, N. Y.

FREEMAN, WELDON WINANS
President, Union Gas & Electric Co., Cor. 4th and Plum Sts., Cincinnati, O.

GAGE, HENRY PHELPS
Physicist, Corning Glass Works, Corning, N. Y.

GILCHRIST, JOHN F.
Vice-president, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

GRANT, A. W., JR.
Photometrical Department, United Gas Improvement Co., 1401 Arch St., Philadelphia, Pa.

HAYLLAR, BENJAMIN, JR.
Member of firm, Imperial Electric Co., 1022 Arch St., Philadelphia, Pa.

HAYNES, PIERRE EVAN
Chief Chemist, Linde Air Products Co., 42nd St. Building, New York, N. Y.

HIRSCH, H. HIRAM
Hirsch Electric Mine Lamp Co., 314 N. 12th St., Philadelphia, Pa.

HOEVELER, JOHN A.
Illuminating Engineer, National X-Ray Reflector Co., 235 W. Jackson Blvd., Chicago, Ill.

HOWELL, JOHN W.
Engineer, Lamp Works, General Electric Co., Harrison, N. J.

JOHNSON, WALTER H.
Vice-president, Philadelphia Electric Co., 1000 Chestnut St., Philadelphia, Pa.

JONES, WM. R.
Superintendent of Buildings and Grounds, University of Pennsylvania, Engineering Building, Philadelphia, Pa.

JUNKERSFELD, P.
Assistant to Vice-president, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

KEGERREIS, ROY
Teacher, 53 Wendell St., Cambridge, Mass.

KENNELLY, A. E.
Professor of Electrical Engineering, Harvard University, Cambridge, Mass.

KRANTZ, HUBERT F.
President and Treasurer, Krantz Mfg. Co., Inc., 160 Seventh St., Brooklyn, N. Y.

KRUESI, PAUL JOHN
General Manager, American Lava Co., 27 William St., Chattanooga, Tenn.

LEWINSON, LEONARD J.
Engineer of Lamp Tests, Electrical Testing Laboratories, 80th St. and East End Ave., New York, N. Y.

LEWIS, F. PARK
Physician, 454 Franklin St., Buffalo, N. Y.

LIEB, JOHN W.
Vice-president, The New York Edison Co., Irving Place and 15th St., New York, N. Y.

LITLE, THOMAS J., JR.
Engineer, Welsbach Co., Gloucester, N. J.

MACKAY, G. M. JOHNSTONE
Research Engineer, General Electric Co., Schenectady, N. Y.

MAILLOUX, C. O.
Consulting Engineer, 20 Nassau St., New York, N. Y.

MANWARING, A. H.
Electrical Engineer, The Philadelphia Electric Co., 1000 Chestnut St., Philadelphia, Pa.

MAXWELL, ALEXANDER
Laboratory Engineer, The New York Edison Co., 92 Vandam St., New York, N. Y.

MAYER, JOSEPH
President, The Coast Gas Co., 511 9th Ave., Belmar, N. J.

MEYER, JOHN W.
Assistant Manager Sales Department, Philadelphia, Electric Co., 1000 Chestnut St., Philadelphia, Pa.

MINICK, J. L.
Foreman, Electrical Department, Pennsylvania Railroad Co., Motive Power Building, Altoona, Pa.

MORRISON, GEORGE F.
Manager Lamp Works, General Electric Co., Sussex St., Harrison, N. J.

MURPHY, FRANCIS HAYES
Illuminating Engineer, Portland Railway Light & Power Co., Electric Building, Portland, Ore.

MURRAY, THOMAS E.
Vice-president, The New York Edison Co., 124 E. 15th St., New York, N. Y.

MCKAY, WILLIAM A.
Assistant to Commercial Engineer, Westinghouse Lamp Co., 1261 Broadway, New York, N. Y.

MUTH, GEORGE B.
Assistant to District Manager, The Philadelphia Electric Co., 1000 Chestnut St., Philadelphia, Pa.

OSBORN, FREDERICK A.
Professor of Physics, University of Washington, Seattle, Wash.

O'SHEA, JAMES P.
General Sales Agent, Cooper-Hewitt Electric Co., 730 Grand St., Hoboken, N. J.

PACE, T. J.
Assistant to Manager, Supply Department, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

PAGE, ALMON D.
Sales Manager, Edison Lamp Works of General Electric Co., Harrison, N. J.

PARKHURST, GEORGE W.
Secretary, The New York Mutual Gas Light Co., 36 Union Square, New York, N. Y.

PIKE, CLAYTON W.
Chief, Electrical Bureau, Philadelphia, 616 City Hall, Philadelphia, Pa.

POWER, WILLIAM R.
Superintendent, Consolidated Light, Heat & Power Co., 1043 4th Ave., Huntington, W. Va.

RANDALL, J. E.
Consulting Engineer, National Lamp Works of General Electric Co., Nela Park, Cleveland, O.

REGAN, WILLIAM M.
Chemist and Photometrist, Consolidated Gas Co., 501 E. 21st St., New York, N. Y.

RHODES, SAMUEL G.
Engineer, Meter and Test Department, The New York Edison Co., 104 E. 32nd St., New York, N. Y.

RISDON, TURNER J.
Commercial Inspector, The Philadelphia Electric Co., 1000 Chestnut St., Philadelphia, Pa.

ROBB, WILLIAM LISPENARD
Professor of Electrical Engineering, Rensselaer Polytechnic Institute, P. O. Box 592, Troy, N. Y.

ROLINSON, W. H.
Commercial Engineer, Westinghouse Lamp Co., 1261 Broadway, New York, N. Y.

RUSSELL, CHARLES J.
Manager Sales Department, The Philadelphia Electric Co., 1000 Chestnut St., Philadelphia, Pa.

SCHILDHAUER, EDWARD
General Manager, New Castle Construction Co., 30 Church St., New York, N. Y.

SEILER, ALVIN
Agent, Westinghouse Lamp Co., Greensburg, Pa.

SKIFF, W. M.
Manager Engineering Department, National Lamp Works of General Electric Co., Nela Park, Cleveland, O.

SMITH, FRANK W.
Vice-president, The United Electric Light & Power Co., 130 E. 15th St., New York, N. Y.

SPROULE, THOMAS
Assistant Engineer, The Philadelphia Electric Co., 1000 Chestnut St., Philadelphia, Pa.

STANDISH, MYLES
Ophthalmologist, 72 St. James Ave., Boston, Mass.

STEVENOT, J. E. HAMILTON
Consulting and Constructing Engineer, P. O. Box 795, Manila, Philippine Islands.

SWEET, ARTHUR J.
Consulting Engineer, Vaughn, Meyer & Sweet, 1007 Majestic Building, Milwaukee, Wis.

THOMAS, CHARLES G. M.
President, New York & Queens Electric Light & Power Co., 444 Jackson Ave., Long Island City, N. Y.

UPTEGRAFF, W. D.
President, The Union Switch & Signal Co., 200 Westinghouse Building, Pittsburgh, Pa.

VAN HORNE, JOHN S.
Lamp Engineer, The V. & D. Electric Co., Franklin, O.

VAN RENSSELAER, SCHUYLER W.
Illuminating Engineering Bureau, The New York Edison Co., 130 E. 15th St., New York, N. Y.

WESTON, EDWARD
Electrical Engineer and President, Weston Electrical Instrument Co., Waverly Park, Newark, N. J.

WRAY, J. G.
Chief Engineer, Central Group Bell Telephone Companies, 212 W. Washington St., Chicago, Ill.

WRIGHTINGTON, EDGAR N.
Second Vice-president, Boston Consolidated Gas Co., 24 West St., Boston, Mass.

YOUNG, EDWIN S.
Assistant Secretary, The New York Mutual Gas Light Co., 36 Union Square, New York, N. Y.

Fifteen associate members were transferred to the grade of member at a Council meeting held January 13, 1916:

BENJAMIN, R. B.
President, Benjamin Electric Mfg. Co., 120 S. Sangamon St., Chicago, Ill.

CLIFFORD, H. E.
Professor of Electrical Engineering, Harvard University, Pierce Hall, Cambridge, Mass.

CURRIER, BURLEIGH
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COAL MINE ILLUMINATION AND ITS RELATION TO ACCIDENT PREVENTION AND MINERS' NYSTAGMUS.*

BY R. E. SIMPSON.

Synopsis: The paper first deals with the various types of portable lighting units that have been or are now in use in coal mines. The various points where the incandescent electric lamp may be used and their importance in safe coal mine operation are indicated. The causes, symptoms, and preventative means of miners' nystagmus are discussed in the latter part of the paper.

Coal mining ranks as one of the most dangerous industries in which man is engaged, and this is true not only because of the high accident rate, but also because of the serious nature of many of the accidents. Instant death, or injuries resulting in total disability, are much more frequent in coal mining than in most other industries. One of the factors that contributes to this high accident rate is the inadequacy of the illumination in coal mines. There are but a very few if any industries in which the illumination is so wretched, and at the same time where good illumination is so necessary for the safety of the men.

But the problem of providing adequate illumination in a coal mine is not easily solved. The use of illuminating gas is out of the question; first, because the open flame will ignite methane and cause explosions; and, second, because illuminating gas is itself so explosive that no mine owner would permit the introduction of such a hazardous element in the mine; and lastly because the cost of piping would be prohibitive. The use of electric light is likewise impractical, because the cost of wiring the miles and miles of entries and working places precludes it, ex-

* A paper read at a meeting of the Philadelphia section of the Illuminating Engineering Society, November 19, 1915.

cept at important switching points. There remains, then, only some form of portable light available for general coal mine lighting.

In the early days of coal mining, and even to-day in some instances, candles were used at the working faces and along the haulage roads. The atmospheric conditions were such in the mines that each candle rarely gave a full candlepower, in fact a fair average would be 0.8 candlepower. When one considers the fact that the coal miner is surrounded by black coal reflecting very little of the incident light, this illumination from one candle in a room 20 feet wide cannot be called adequate. Moreover, since no open-flame light sources of any type should be allowed in gaseous mines, this proscription of course includes candles, and constitutes another argument against them.

The open-flame oil lamp consisting of a metal oil container and a spout for the cotton wick was next introduced. The light from lamps of this type ranged from 1 to 4 candlepower, the variation depending on the size of the wick and the grade of lard, cotton seed oil, or crude petroleum used for fuel. Either lard or cotton seed oil is preferable to crude petroleum because better color of light is obtained with little contamination of the air by the products of combustion. Crude petroleum is much cheaper, however, and it is generally used in the large lamps worn by drivers. The light from petroleum lamps is of a deep orange tint, the upper portion of the flame becoming deeper in color till it merges into a column of smoke. This latter feature is decidedly objectionable in working places where the ventilation is poor, in that a couple of these lamps will soon produce a zone of smoke near the roof, which it is impossible for the miners to avoid while working in the low head room prevalent in coal mines. These lamps are also subject to criticism in that they give a flickering light which is very trying on the eyes.

All these open-flame lights exposed the miners to the danger of explosions of methane (commonly called "gas" by the miners), however, and this condition made necessary the use of a light source which would not ignite this gas. The safety lamp, which is essentially a cylinder of gauze placed about the flame, not only prevents the flame from igniting any gas that may be present,

but is also used to indicate the percentage of gas present by the variation in size of the cap at the tip of the flame. When, however, considered for illuminating qualities only, the safety lamp leaves much to be desired. Even when new, or when thoroughly cleaned and trimmed, the safety lamp seldom gives more than 1 candlepower; and when in use the gauze soon becomes clogged with coal dust and smoke so that the light emitted ranges from 0.2 to 0.5 candlepower. Both the top and the bottom of the lamp cast shadows which greatly increase the chance of stumbling and prevent the miners from noting dangerous conditions in the roof.

The acetylene lamp, known among miners as the "carbide lamp," is by far the best open-flame lamp in use in coal mines today. With a reflector equipment, and a flame 1 to 1¼ inches (2.54 to 3.17 cm.) long the carbide lamp gives 4 to 6 candlepower, head-on, and ¾ to 1½ candlepower at right angles to the flame. The color of this light is whiter than that of the other lamps mentioned, and is practically free from smoke, while the products of combustion are not injurious to health. Since this light is produced by the burning of a gas there is no danger of sparks falling and igniting explosives, although the flame of the carbide lamp sets fire to inflammable material more quickly than oil or candlepower flames do. More important still is the increased safety of the miner, gained by the better light which enables him to examine more easily and more thoroughly his working place and detect dangerous roof conditions. These facts taken in connection with the better all-around illumination, account for the popularity of this lamp.

On the other hand, there are some features about the carbide lamp that tend to make its use hazardous. For instance, a carbide lamp will remain lighted in an atmosphere containing considerably less oxygen than is necessary for the continued burning of an oil lamp or candle. This means that a miner using a carbide lamp may be at work in air containing too little oxygen, and therefore a correspondingly increased amount of carbon dioxide or black damp, without being warned of this condition by the diminishing light from his lamp, though this condition of the air may be bad enough to injure his health or jeopardize his life. Another bad feature of the use of the carbide lamp is that if a quantity of calcium carbide accidentally comes in contact with

water, acetylene gas will be generated, and if this gas is ignited it will cause an explosion or severe burns. Moreover, a sudden jar or shock to the air, such as that produced by firing a shot, may extinguish the flame of a carbide lamp. For this reason it is not to be depended on as the sole means of light for motormen, drivers, or trip riders.

Four kinds of portable lamps have now been mentioned. The fifth and last that is to be discussed is the storage-battery electric lamp, commonly known as the electric cap lamp. This lamp has many advantages over the other types already discussed. In the first place, since the light source is completely enclosed and burns in vacuum, there is little likelihood of gas ignition. In the second place, neither smoke nor odor is given off by the electric lamp. Moreover, when equipped with a proper reflector, a lamp of 1 candlepower will give forth a beam of light measuring five to ten times as great, through an angle of 130°. As these advantages become better known, it may be expected that this type of lamp will replace the other types now in use.

In the first part of this paper, while considering the possibility of the use of the incandescent electric lamp in coal mines, it was stated that there were some conditions under which that type of lamp might be used. The introduction of electricity in coal mines, for haulage and other power purposes, has provided the means of making use of this lamp for lighting important parts of the mine, such as shaft bottoms, turnouts, and switching points. Its use is limited, however, by the prohibitive expense of wiring, to these points or other points where electricity is available.

In considering the problem of coal-mine illumination it is well to remember that even though these improved types of lighting units be used, there still remain many inherent obstacles to the efficient illumination of the mines. Among these obstacles is the fact that the roof, bottom, sides or ribs, and face are composed of coal, slate, or rock, all of which absorb a great deal of light. Another obstacle is that the majority of underground employees of a coal mine must work in places of low head room, ranging from 2½ to 6 feet (0.76 m. to 1.82 m.), the latter height being rare at present. Moreover, in the entries and working places there are many obstructions to the light rays, such as props, gobs, and curves. If the length of the main haulage road and the

numerous side entries be totaled it will be found that there are several miles of these underground passageways in an average coal mine. To illuminate these entries to a degree comparable with suburban street lighting would be prohibitively expensive, especially so, if the damage that might be done by derailments and roof falls is borne in mind. Moreover, no very great advantage would be gained by such an installation.

The lighting units suitable for coal-mine illumination may then be divided into two main classes; first, portable units at the working places, and second, permanent units at the more important points along the haulage roads, with auxiliary portable units for drivers, motormen, and trip riders. Portable units are the only practical means of providing illumination for the actual production of coal, that is mining and loading. Of these units the electric cap lamp for all classes of mines and the carbide lamp for non-gaseous mines are the best. With one of these lamps on his cap the miner has no light rays within the range of vision, and always has a beam of light directed on his work. He can therefore more readily detect dangerous roof conditions, and can provide for his safety by taking down the loose slate or rock, or by supporting it with a prop. When walking into or out of the mine or about his working place he also has better light, with a correspondingly smaller chance of stumbling. In fact, any kind of work which a miner may be called on to do can be done more efficiently and with less danger to himself under the light from either of these two types of lamps than with other portable mine lamps.

The use of the second kind of lighting unit, the incandescent electric lamp, where electric power is available, has given the best results in the other main operation of coal mining, the transportation of the coal from the working places to the tipple or breaker. One point that especially needs to be well illuminated is the turnout which is almost always found extending back some distance from the shaft bottom in shaft mines. Every car that goes into or out of the mine must be handled at this point, which is consequently the busiest part of the mine. Whenever possible, the turnout at this point is constructed with an upgrade from the shaft bottom so that the loaded cars will run by gravity, in very much the same manner as the movement of railway cars is

facilitated by a "hump" in freight yards. One man at least must be employed to uncouple the cars and drop them to a point where they can easily be run on to the cage. He must so perform his work that cars are always ready for the cage, and at the same time prevent cars from crashing into the cage or shaft structure. There is a constant switching of empty cars on to the tracks that lead from the cage, and of loaded cars from the tracks leading to the cage. At the other end of the turnout it is essential for the safety of all concerned that the motorman or driver should be sure that the switches are properly set and the tracks clear. It is evident that the illumination here should compare favorably with that provided in the business sections of our streets, the space in the immediate vicinity of the shaft bottom having a higher intensity than any other point.

The same conditions prevail in a lesser degree at the other turnouts or switching points on the haulage road. At the junction of an entry with the main haulage road good illumination should be provided to indicate to the motorman when to reduce speed to take the curve and switches safely, and also to enable him to see that the switches are properly set.

In addition to the possibility of violent accidents caused by poor illumination as discussed above, there is another hazard of less violent nature—really an occupational disease—that is also due to poor illumination. This is the disease of miners' nystagmus, to which considerable attention has been given during the past decade, particularly in European coal-producing countries. From available statistics it seems that the disease is more prevalent in Europe than in the United States. No doubt this condition is accounted for in part by the fact that thinner coal veins are worked abroad, and also by the fact that a higher proportion of European miners use safety lamps and therefore work under poor lighting conditions. The matter has become so serious, both in the number of men whose sight is affected by the disease and in the number of men injured because of sight failure, that governmental investigations have been made in Great Britain.

The symptoms of the disease are inability to see at night, coupled with a dread of bright light. Lighted lamps dazzle the eyes, and at a later stage the lamps and surrounding objects appear to dance or jump about. Severe headaches, giddiness, and

dizziness, are characteristic of nystagmus patients when they bend over or exert themselves. An involuntary, rotatory oscillation of the eyeballs, blinking of the eyelids and eyebrows, a backward inclination and shaking of the head and sometimes of the shoulders, are the more common physical evidences of the disease in its later stages. The eyeball oscillations in some cases have been as frequent as 150 per minute. Under these conditions, or even in cases where the oscillations are considerably less in number, there is little wonder that objects seem to dance.

There are two distinct reasons advanced by opposing investigators as to the cause of nystagmus. Such observers as Snell, Dransart, and Nieden have consistently advanced the view that the position assumed by the miner at his work is the cause of the disease. On the other hand Dr. Court, Dr. Llewellyn, and with rare exceptions the miners themselves, have always attributed the disease to the lack of sufficient light, and considered the position of the miner as having little influence. Referring to the first view it is contended that when a miner is lying down undercutting the coal, or when his head is bent to one side while drilling holes, his eyes necessarily assume an upward, oblique position. When this is continued for long periods each day certain muscles of the eye are so weakened that they do not function properly, hence, the oscillations. This seems to be a logical explanation of the oscillatory movements of the eyeballs, but does not clearly account for the dread of light, or dazzle to the eyes characteristic of nystagmus patients. This condition seems to indicate retinal exhaustion.

On the other hand, it is held that the deficient illumination ranging from 1/50 to 1/10 foot-candle, coupled with the nonreflecting surfaces, prevents the formation of definite images on the retina. This causes indecision on the part of the controlling mechanism of the brain, so that irregular incoordinate movements of the eyeballs follow. In support of this view there is the fact that while nystagmus is very common in coal mines in which safety lamps are used, it is rarely found in coal mines having open lights, and is unknown in metalliferous mines where, because of the use of open light and the light colored surroundings, better illumination prevails. Additional evidence that inadequate illumination, and not the position of the miner, causes

the disease may be had from data gathered by investigators in the coal mines of England and Wales. It was found that in mines where lamps giving ¼ candlepower were used 2 per cent. of the men had nystagmus, while in the mines where ½ candlepower lamps were used only two fifths of 1 per cent. of the men showed symptoms of nystagmus. The relative frequency of nystagmus cases among miners using safety lamps, and those using open flame lamps or candles was found to be six to one. The question as to the comparative effect of the miners' position and the illumination on the frequency of nystagmus cases was also considered. It was found that in coal mines 4 feet or less in height, in which the miners used open-flame lamps or candles, and in which they must do a great part of the work while lying on the side, nystagmus was unknown or very rare. On the other hand, in mines 4 to 7 feet in height, in which safety lamps are used for lighting and in which not so much work on the side is necessary, nystagmus is very common. These investigations lead one to the conclusion that the lack of sufficient illumination is the real cause of the disease, and that the position of the miner has little or no influence in causing it.

In endeavoring to suggest a system of illumination which will prevent miners from contracting this disease, certain factors must be taken into account. In the first place the illumination at the coal face depends primarily on the candlepower of the light source and the distance between the light source and the coal face. I have already referred to the inadequacy of the illumination furnished by the candle, oil open-flame lamp, and the safety lamp; and in the case of the safety lamp the illumination is further reduced by the necessity of placing the lamp a few feet from the work. Of the practical, portable light sources there remain only the carbide lamp and the electric cap lamp. Of the two, the electric lamp is the better for all classes of coal mines, because of the greater amount of useful light emitted and the greatly reduced chance of gas and dust explosions. Moreover, both the carbide lamp and the electric cap lamp can be worn on the miner's cap, so that they are at all times as close to the work as the miner himself and therefore give good light on the work. In addition, the reflectors on these lamps concentrate the light waves in front of the miner where the light is

most needed. This concentration of light cannot well be obtained with the other light sources mentioned.

Another factor influencing the intensity of the illumination is the surroundings of the miner. Since practically all the incident light is absorbed by the dark ribs, roof, and bottom in a coal mine, a change of light source will have no effect on the intensity of illumination so far as reflection is concerned. But if the atmospheric conditions are poor a change of light source will affect the illumination. As has already been pointed out, oil lamps in a poorly ventilated work place soon produce a smoky atmosphere, and this of course greatly reduces the intensity of illumination. The deposit of combustion products on the gauze of the safety lamp, a falling in the percentage of oxygen in the air, or the presence of vapor in the air, all have the same effect of reducing the efficiency of the safety lamp. The carbide lamp is not greatly affected by any of these conditions, and the electric lamp not at all.

In summing up from all the data of this paper, five conclusions are to be drawn. First, that for the actual mining and loading of coal portable light sources are the only practical means of furnishing illumination. Of these portable light sources the electric cap lamp ranks first for general usefulness, followed by the carbide lamp for use in non-gaseous mines.

Second, for the important points in the transportation system, that is the haulage roads, shaft bottoms, and stables, as well as the supply rooms and pumping stations, small-sized incandescent lamps are the most practical and efficient units.

Third, motormen, drivers and trip riders should supplement the permanent incandescent lighting with portable oil lamps having wicks at least ½ inch in diameter.

Fourth, if the working face is well illuminated there is less chance of dangerous conditions escaping notice, and less chance for nystagmus to develop among the miners.

Fifth, the better illumination provided by incandescent lamps along the haulage way, will tend to reduce the hazards of collisions, derailments and other forms of haulage accidents, thus increasing the general efficiency in the transportation of the coal.

DISCUSSION.

MR. EDWIN M. CHANCE: It seems to me that a sharper distinction should be made between the problem of illuminating gaseous and non-gaseous mines. In the first place the relative importance of illuminating non-gaseous mines is far greater than that of illuminating those that may be classified as fiery, as the tonnage of coal mined from the former is far greater than that mined from the latter and hence the number of men employed in the former is greater than that in the latter. It has been found that a source of illumination that will be satisfactory in one type of mine may not be as well suited to the other. It is for this reason that the open acetylene lamp has attained its present importance. To my mind Mr. Simpson's first conclusion should be restated to read that the acetylene lamp is to be preferred in non-gaseous mines because of its greater illuminating power and its cheapness of operation, while the portable electric lamp when suitably safeguarded is to be preferred in gaseous mines.

Mr. Simpson calls attention to the supposed danger in using acetylene lamps where blackdamp may be encountered. This danger is non-existent, as the acetylene lamp gives warning of the presence of blackdamp long before this gas has reached a proportion that might endanger human life. The open oil lamp will be extinguished when the oxygen content of mine air has fallen to about 15 per cent. The acetylene lamp loses its brilliancy of illumination when the oxygen content has fallen to about 14 per cent. and is extinguished at about 12 per cent. of oxygen. Human life will not be endangered when the oxygen content of the air has fallen to but 10 per cent. provided no extraordinary physical exertion is indulged in and as low a content as 8 per cent. can be borne. Mr. Simpson appreciates the fallacy of the blackdamp bogie in that he recommends the use of the portable electric mine lamp. Now if the danger from blackdamp were at all real, the use of the electric lamp would be unreasonable, as with the electric lamp no indication whatever is given of the condition of the mine atmosphere.

The importance of adequate illumination of coal mines cannot be too heavily stressed, as by this means the efficiency of the

mine worker will be considerably increased. He will, in flat work, be able to clean his coal more thoroughly and with less effort, and in every case will also have a better knowledge of the condition of his working place, and while this knowledge will not compel him to take the precautions indicated, it will make their necessity evident at the least.

In conclusion, the fact that from 400,000 to 600,000 acetylene lamps are in use in the mines to-day is a fair criterion of the relative value of this source of illumination and shows that the mine worker appreciates it at its true value.

MR. R. E. SIMPSON: Mr. Chance suggests that the first conclusion of the paper be restated so as to give preference to the acetylene lamp in non-gaseous mines on the strength of its greater illumination and cheapness of operation, while the electric cap lamp is to be preferred in gaseous mines. The acetylene lamp is admittedly far superior, from a light giving standpoint, to all other types of open flame lamps, but according to available test data it is inferior to the commercial electric cap lamp. Records of the cost of operation of both types of lamps in this country and in Europe show the acetylene lamp as the less expensive. The illumination provided by either the acetylene lamp or the electric cap lamp in coal mines is far below that provided in the average industrial plant, and since adequate illumination in coal mines tends to insure safer working conditions the expense involved in producing this illumination should not be the determining factor.

The chance of unfortunate results due to the lack of oxygen content in mine air are rather remote, and the comments of Mr. Chance on this subject with respect to the acetylene lamp apply even more forcibly in the case of the electric cap lamp.

MR. A. C. MORRISON: The acetylene or carbide lamp represents a paradox in that, as shown by the previous speakers, it furnishes better illumination without hazard and without smoke, and I may add at lower cost. Better illumination means greater working efficiency and the physiological effect upon the miner in producing better contentment must follow.

The subject of blackdamp has been mentioned by Mr. Simpson and it may perhaps be interesting to those present to know that

in the literature of the subject of mine gases there is no true definition of blackdamp. I find that blackdamp is usually described as carbon dioxide while as a matter of fact blackdamp is really composed, as shown by analysis, of carbon dioxide and nitrogen in various proportions. Nitrogen has no effect upon the human system but carbon dioxide has—it also has an effect on flame extinction. Moreover in the mine carbon dioxide is not a pleasant gas. Blackdamp is the product of the slow combustion of coal in contact with the air in the mine or the accumulation of such products in pockets. Following the laws of combustion, the oxygen of the air combines with the carbon of the coal, forming carbon dioxide. The nitrogen of the air, from which the oxygen has been taken is left behind. Following the laws of gases, the carbon dioxide, when the combustion is complete, should theoretically occupy exactly the same space as the oxygen which went into combination; but as a matter of fact part of the oxygen is absorbed and fixed by the coal substance itself or the pyrites which it contains, so that the yield of carbon dioxide under these conditions is but a proportion of the theoretical quantity. The result is that true blackdamp may be, I think, properly defined as a mixture of carbon dioxide and nitrogen in the proportion of one of carbon dioxide to five of nitrogen. The analysis of mine air collected from different sources widely scattered discloses the fact that the amount of carbon dioxide in blackdamp seldom reaches this ratio or a dangerous percentage in mine air. When I say dangerous, I don't mean as the physicians here will note that 2 or 3 per cent. of carbon dioxide is physiologically safe to be breathed over long periods, but I do mean that the quantity present, as shown by analysis, is not sufficient in active workings to cause immediate danger of such a character that the miner cannot escape. It must, therefore, be clear that when we speak of blackdamp, we must not consider 25 per cent. blackdamp as 25 per cent. carbon dioxide but rather as a mixture of nitrogen and carbon dioxide aggregating 25 per cent., of which the nitrogen is 20 per cent. and the carbon dioxide may be 5 per cent., though it is not always in this proportion. It is interesting to note that the concensus of medical opinion now is that the stimulus to breathing is not the absence of oxygen, but the presence of carbon dioxide in the lungs. Analysis of air, taken

directly from certain parts of the lungs, shows that between 5 and 6 per cent. of carbon dioxide is normally present. If this amount is increased slightly, stimulating influence becomes more active and one breathes more frequently and with increasing vigor.

This fact will have a distinct bearing upon the results of certain experiments which I personally witnessed. A rabbit was put into a tight box and subjected to the influence of carbon dioxide which was rapidly increased up to 27 per cent. As the quantity of carbon dioxide approached the maximum, the discomfort of the rabbit increased and partial paralysis and subsequent unconsciousness was reached at 27 per cent. or slightly beyond. Subsequent experiments on man in the same apparatus indicated increased breathing after 3 or 4 per cent. had been reached; vigorous breathing and evident distress when 7 per cent. was reached. Both the rabbit and the man immediately recovered from the effects of exposure to carbon dioxide when brought into the open air, the man complaining of a slight headache after the experience; the rabbit made no report but evidently enjoyed a carrot with which he had been rewarded. It would seem from this experiment that as soon as carbon dioxide in the atmosphere produces or exceeds the amount normally present as a stimulus to breathing in the lungs a vigorous physiological effect is produced and that this constitutes an active physiological warning which the miner will certainly heed. Neither oil lamps nor acetylene lamps will show any indication of the presence of pure carbon dioxide in this percentage. When, however, carbon dioxide and nitrogen are present, it means in effect, the reduction of the oxygen content of the mine air. Careful physiological experiments conducted by the best authorities have disclosed the fact that imminent danger is reached when the oxygen content of air is reduced to 7 per cent.; 8 per cent. is less dangerous but not in the zone of safety; 10 per cent. will apparently maintain life indefinitely but with some discomfort and oil flames of different characters go out in perfectly still atmosphere when the oxygen content is reduced to varying points between 17 and 14 per cent. The acetylene flame will go out in a perfectly still atmosphere when the oxygen content is reduced to about 12 per cent. If carbon dioxide is present as a part of the atmosphere, it has an extinctive effect on the flame which will cause it to go

out sooner. If the flame of either the oil or the acetylene lamp is subjected to motion or a slight draught, it will be extinguished at a higher percentage of oxygen, the acetylene being more easily affected than the oil. It is, therefore, clear that both the oil and the acetylene flame give adequate warning of an absence of oxygen and adequate warning of the presence of normal blackdamp and that there is a wide margin of safety in the oxygen content of the air after the acetylene flame has been extinguished.

A word may be said in regard to calcium carbide, and to the acetylene lamp situation in general. Calcium carbide will not explode, will not ignite, and is not affected by concussion. Calcium carbide exposed to mine air saturated with moisture will slowly disintegrate but the quantity of moisture is not sufficient to make an explosive mixture. The fact that from four to six hundred thousand acetylene lamps are now in use in the mines and have been for several years and that the accidents from their use have been trivial, consisting in three conspicuous cases of the loss of a thumb because a man was fooling with a lamp which was hermetically sealed; the experience of a miner who spit a mouthful of tobacco juice into the carbide of his acetylene lamp while another was burning on his head and as a result lost his eyebrows; the case of five miners who tried to gather up, with their lamps burning, some carbide which they had dropped into a puddle of water; none was injured but all well scared. Perhaps one or two other similar trivial experiences constitute the total hazard. There has never been an accident due to blackdamp caused by the use of acetylene.

These facts constitute to an insurance man the very best actuarial evidence of the safety of the new illuminant and, as I said before, acetylene represents the remarkable paradox of better light, more light, a healthful light and no smoke, at less money.

Mr. R. E. Simpson: Mr. Morrison defines blackdamp as a mixture of carbon dioxide and nitrogen in the theoretical proportion of one part of carbon dioxide (by volume, I assume) to five of nitrogen. If his previous statement about carbon dioxide occupying the same space as the oxygen from which it is formed, is true (and it is true if no oxygen is otherwise used up), blackdamp, as he defines it must consist of one volume of carbon

dioxide to four parts of nitrogen, since air contains approximately one volume of oxygen to four of nitrogen. Mr. Morrison accepts this view a little further on in the discussion wherein he gives the constituent parts of 25 per cent. blackdamp.

Mr. Morrison's definition of blackdamp as a mixture of carbon dioxide and nitrogen involves a theory of the cause of blackdamp. It is conceivable at any rate that coal may give off carbon dioxide just as it gives off methane, and without any slow combustion. Moreover, a black-powder explosion might generate considerable carbon dioxide without any corresponding generation of nitrogen or absorption of oxygen in or from the air. Though these points are interesting they are largely academic in their nature and are not germane to the subject of the paper except insofar as they affect the performance of the illuminants and the safety of the men.

A BOX PHOTOMETER.*

BY L. O. GRONDAHL.

Synopsis: This paper deals with the subject of integrating photometry and consists of three parts, as follows: I. Review of results obtained by other experimenters on the performance of the Ulbricht sphere. II. Results of earlier experiments on box photometer. III. Results of present investigation on: (1) Oblong rectangular box; (2) Box with corners eliminated; (3) Cubical box with corners eliminated.

The recent development of the concentrated filament lamp and the consequent necessity of rating lamps in terms of lumens or mean spherical candlepower, rather than mean horizontal candlepower, make it seem especially appropriate at this time to consider the subject of integrating photometers. Of these, the Ulbricht sphere at present holds the field to the nearly complete exclusion of other methods. This integrator has some disadvantages, among which is its first cost, due to the difficulty in making a large spherical surface. This, together with a number of statements in the literature to the effect that a box or an enclosure of any shape whatever would do as well as a sphere, led to a series of experiments on boxes, rectangular and otherwise, in the hope that something would be found to replace the sphere. In order to give a comparison between the performance of the box photometer and that of the sphere, it has been thought advantageous to review some of the results of earlier experiments with the sphere, as well as the experiments of Wild on the box photometer which until very recently had not come to the writer's attention.

The result of the present investigation is to corroborate the statements of those who have said that a box may be used instead of a sphere. To compare sources of different distributions, however, it is necessary to use a box that is cubical, and its accuracy is still further increased by eliminating the corners and thus approximating a sphere. This being done, and proper pre-

* A paper read at the mid-winter convention of the Illuminating Engineering Society New York, February 10, 11, 1916.

cautions being taken in regard to the screen, and in regard to the dark part of the units introduced, the box yields satisfactory results. When the light units all have the same distribution and are similarly oriented with reference to the dimensions of the box, the interior may undoubtedly have any shape. Since writing this paper, it has come to the author's notice that a construction similar to the one used in this work has been suggested earlier, and has in one case been applied practically.

I. THE ULBRICHT SPHERE.

The following consideration shows that the intensity of illumination at any point on the interior of a sphere is proportional to the total flux from the source contained therein, provided only that the direct rays from the lamp are screened off. Let the

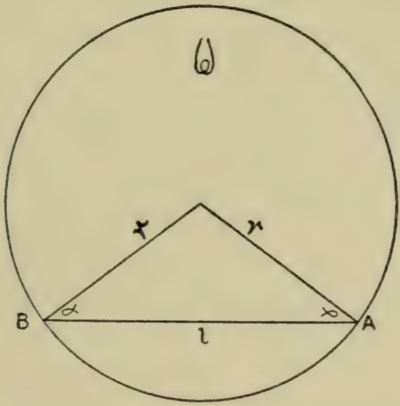

Fig. 1.—Theory of the integrating sphere.

direct illumination at a point A Fig. 1, be I_A. Then the intensity of illumination at any point B due to light reflected from a small area ds at A will be $KI_A\ ds \frac{cos^2 \alpha}{l^2} = KI_A\ ds \frac{1}{4r^2}$. If this is integrated over the whole sphere we get $KF \frac{1}{4r^2}$. And if we take successive reflections into account, we have $KF \left[\frac{1}{4r^2} + \left(\frac{1}{4r^2}\right)^2 + \left(\frac{1}{4r^2}\right)^3 + \left(\frac{1}{4r^2}\right)^4 + \text{etc.} \right]$, a quantity which is proportional to F, the total flux of the source. K is the constant

of reflection. This calculation is true only on the supposition that there are no other absorbing surfaces within the enclosure. With a sphere it is necessary to have at least two such surfaces, the screen and opaque parts of the unit. These both introduce errors which may be minimized by the proper choice and arrangements of parts. Present practise seems to be to use an opaque screen and to place the lamp somewhat above the center of the sphere.

The following data and curves will give some idea of the efficiency of the sphere. Ulbricht[1] in his first paper on the subject describes an experiment with a carbon filament lamp one side of which was covered with opaque white paint. Beginning with the painted side towards the window and turning through 90° at a time about its vertical axis he obtained the following series of readings: At 0°, 100; at 90°, 101.3; at 180°, 98.1; at 270°, 100.

An experimental test is reported by Bloch[2] and is given in part in Tables I and II.

TABLE I.—EFFECT OF POSITION OF LAMP IN SPHERE.

			Source at center		$h/r = 0.1$	
Source	Scp.	Relative value	Readings	Relative value	Readings	Relative value
Carbon filament.....	21.1	1	43	1	44.5	1
6-amp. arc, d. c.	225.0	12.1	473	11.0	550.0	12.3
15-amp. arc, a. c.	1000.0	47.3	1,800	41.8	2060.0	46.3

From this it appears that the eccentric position is better, and it was found also that near this position, small changes in position were immaterial. Values of h/r from 0.08 to 0.15 gave the same result. The error at the center is probably due to absorption rather than to the distribution.

Using the eccentric position, the same author took a series of readings using different sources, the mean spherical candlepower of which were determined by the point by point method.

The constant for the sphere was obtained by means of a carbon filament. Table II gives the results:

[1] Ulbricht; *Electrotech. Zeit.* 29, p. 595, 1900.

[2] Bloch; *Electrotech. Zeit.*, 46, p. 1074, 1905.

TABLE II.—COMPARISONS OF POINT-BY-POINT AND INTEGRATING SPHERE READINGS.

Source	P. by P.	Scp. sphere	Error
Carbon inc.	21.1	21.1	Standard
2 amp. arc.	81.5	84.0	3.1
6 amp. arc.	255.0	260.0	1.9
Flaming arc	1000.0	980.0	—2.0
Right angle arc	750.0	730.0	—2.7
20-amp. arc (Intensified)	2350.0	2400.0	2.1

Accuracy of a slightly higher order seems to have been obtained by some experimenters, but the above is thought to give a fair idea of what may be expected from a sphere.

II. WILD'S EXPERIMENTS ON THE BOX PHOTOMETER.

Wild[3] used for his experiments a box the interior dimensions of which were 22 x 20 x 20 in. (55.9 x 50.8 x 50.8 cm.). He tested the effect of light distribution by means of a tungsten lamp having a very small end on distribution. In his own words: "Tests were made with various screens and windows, and with the lamp and screen in various positions."

The following results were obtained:

1. 10 in. (25.4 cm.) circular screen, 8 in. (20.3 cm.) from front. Lamp 8 in. (20.3 cm.) from back. Clear window. Test plate sees front of screen only and no light from lamp falls directly upon this side. Apparent candlepower 3 per cent. *greater* with lamp filament horizontal than when vertical.

2. Conditions as above, but window covered by thin blotting paper dipped in wax. Difference 2.5 per cent. on changing over.

Rectangular screen, measuring 5 in. (12.7 cm.) by 3 in. (7.6 cm.), 8 in. (20.3 cm.) from front. Lamp 8 in. from back. Waxed blotting paper in window. 1.5 per cent. *more* emission with filament horizontal.

4. Conditions as above, but screen 6.5 in. (16.5 cm.) from front. Same result.

5. 5 x 3 screen, 6.5 in. from front. Four per cent. *less* emission with filament horizontal.

6. 5 x 3 screen, 6.5 in. from front. Lamp 8 in. from back. Window of glass dipped in wax. Difference between vertical and horizontal filament is nil. If lamp is tilted at an angle of 45°, 2 per cent. *less* emission is obtained. No difference could be detected on rotating the lamp suspension so that the tip pointed in turn to all the cardinal points of the compass.

[3] Wild, *Illum. Eng.*, London, vol. III, p. 549, 1910.

Tests 1 to 4 indicate that the presence of foreign bodies is to reduce the effectiveness of the light radiating horizontally.

Test 5 indicates that when no diffusive window is employed the light radiated horizontally is too effective, due to the test plate being directly exposed to a large portion of the back of the box.

Test 6 shows how the effect of foreign bodies may be compensated for. The semi-diffusive window allows just enough light to pass through without diffusion to compensate for the obstruction caused by the screen.

Test No. 6 also shows that the light emitted at 45° is not quite fully effective. Apparently this is due to its having to travel a greater distance before reaching a reflecting surface. This is a fault of the rectangular box, which would not be shared by the globe.

In comparing incandescent lamps of ordinary construction, the variation in the ratio of horizontal candlepower to candlepower at 45° is not very large, and it seems probable that the error due to the rectangular form of box would be smaller than could be detected.

If, however, one had to compare two lamps, the one with vertical filaments and the other with filaments all inclined at 45°, the latter would come out about 2 per cent. too low.

Whilst the tests for effect of distribution were in progress I also made tests to ascertain the best position for the lamp, so that the light emitted should not be affected by small changes of position.

With the 5 x 3 screen 6.5 in. from front and the waxed glass window no change could be detected on moving the lamp from 8 in. from back to 7 or 9 in. from back. At 10 in. from back the light was reduced by about ¾ per cent. and at 11 in. by 3 per cent. It was also found that the lamp could be moved 1 in. up or down or to either side without any change being apparent. The effect of foreign bodies becomes accentuated when the lamp is placed too near to the screen or either wall.

It appears that for testing incandescent lamps a rectangular box constructed on these lines is quite practicable, and in practise is not likely to lead to error if due precautions are taken.

III. THE PRESENT INVESTIGATION.

The data to be reported here as original are the results of observations taken at very irregular intervals during a period of two or three years. They originated in the hope of evading the considerable expense involved in procuring a sphere. The first experiments were made with an oblong rectangular box, the interior dimensions of which were 42 x 33.75 x 24 in. (106.7 x 85.6 x 61 cm.). The interior was in this and subsequent cases painted with lithopone. The mat lithopone to be obtained in the market was found to give the same result as a preparation made by mixing the lithopone powder in turpentine and a slight admixture of

shellac. Both made a very good mat surface although the former may have been a trifle more grayish.

With the oblong box a study was first made of the effect of the position of the window in the side of the box. A corner position and a position near the middle of one side of the box were tried. The corner position was found to be very much more sensitive to the distribution of light from the source than was the central position. It was consequently abandoned. The window was in every case covered by a piece of white translucent glass from a Brodhun street photometer and the latter instrument was used in every case for taking the readings, the test plate being placed in close contact with the window. The

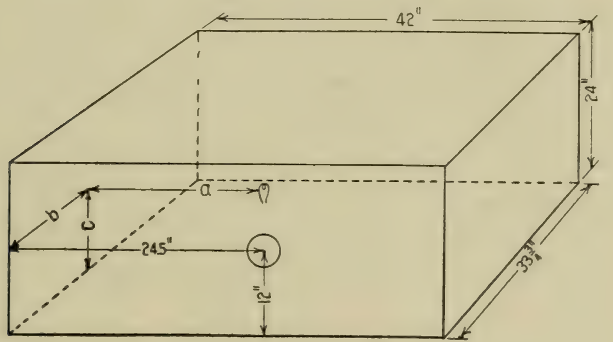

Fig. 3.—Dimensions of first box used.

screen in these early experiments was a piece of mat paper 4 x 6 inches (10.16 x 15.24 cm.) and was placed at about an equal distance from the lamp and the window. The box was placed on the side as indicated in Fig. 3 where the distances *a, b* and *c* are indicated. The tests with this box were performed with a carbon filament lamp placed as indicated in Tables III and IV and on Fig. 4.

Comparisons of readings Nos. 7, 8, 9 and 10 with readings Nos. 11, 12, 13 and 14 in Table III shows that changing the lamp from a position parallel to the length of the box into one at right angles to that position changes the reading by about 4 per cent. As long as the lamp is kept in the former position and near the middle of the box the readings seem very consistent.

TABLE III.—RESULTS WITH OBLONG RECTANGULAR BOX.

Position Axial. $b = 16\frac{7}{8}$ in. $c = 12$ in.

No.	a	Orientation of filament	Reading
1	3″	Vertical with label towards window	29.3
		Horizontal with tip " "	29.7
		" " base " "	31.0
2	5″	" and axis parallel to length of box	30.2
		" and axis perpendicular to line from lamp to window	26.9
		Vertical with label towards window	28.7
3	10″	" " " " "	32.7
		Horizontal " " " "	32.6
4	5″	Horizontal and axis parallel to length of box	30.3
5	10″		34.1
6	15″		40.2
7	20″		41.2
8	25″		41.5
9	30″		41.5
10	35″		41.1
11	20″	Horizontal with tip towards side containing window	42.7
12	25″		43.7
13	30″		44.0
14	35″		42.8

TABLE IV.—EFFECT OF SLIGHT DISPLACEMENT.

Position	Label up	Label toward window
1″ nearer	29.0	29.1
1″ away	28.8	29.0
1″ up	29.8	28.9
1″ dowm	28.9	29.1

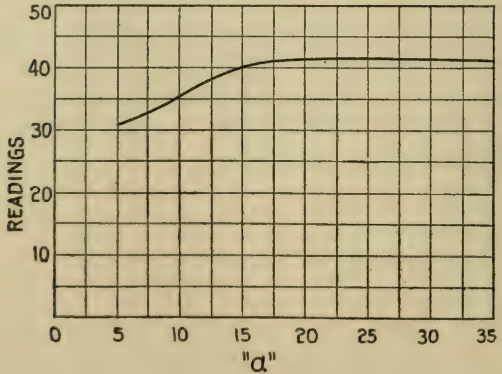

Fig. 4.—Effect of position in oblong box.

The conclusion then agrees with that of Wild; namely that a box constructed along these lines is practical for comparison of incandescent lamps that have a symmetrical distribution.

Box with Corners Eliminated.—It seemed, however, that it might be worth while to try a construction that might be less dependent on distribution. Accordingly, a box was chosen that was more nearly cubical, the dimensions being 26 x 26 x 37 in. (66 x 66 x 94 cm.). The interior was covered with paper and painted as before. The most important change consisted in the elimination of the corners by fitting into them triangles of stiff paper about 16 in. (40.6 cm.) on a side. The box might then be called an oblong decahedron. The approximation to a sphere would of course have been still better and would possibly have yielded better results, had we started with a cube and such a one was later built. The window was placed in the middle of one side and covered as before. Readings were also taken as before with a Brodhun street photometer. Two screens were tried, 5 in. (12.7 cm.) and 10 in. (25.4 cm.) diameter respectively, both painted with lithopone. The large screen when used was placed close to the lamp and in a vertical position; the small screen was placed approximately 8 in. (20.3 cm.) from the window.

The tests in this case consisted of three parts: 1. The comparison of the efficiencies of shades obtained by the point by point method with those obtained by the use of the box. 2. Determination of the effect of position of the source, and 3, study of effect of dissymmetry in the distribution curve of the source. Seven different shades were used, five of which represent fully all the types are reported here. They were No. 1, alba; No. 2, opal; No. 3, a decorative shade; No. 4, a green metal cone painted white on inside with lithopone; No. 5, a porcelain lined cone also green on the outside. The distribution curves for these shades and for the bare lamp are given in Figs. 5, 6, 7, 8, 9 and 10. The last two were considered an especially severe test as in both of these there were practically no light in the upper hemisphere. Table V gives the results obtained for these shades in the box and by the point by point method. In this case the small screen was used and the unit was placed in the center of the box.

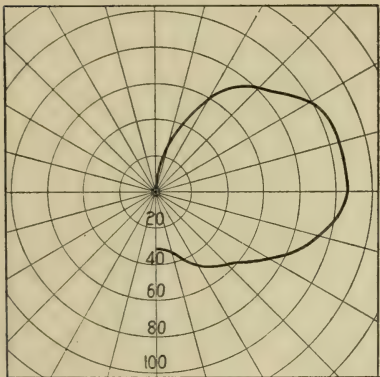

FIG. 5

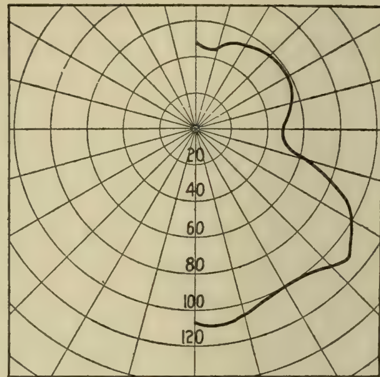

FIG. 6

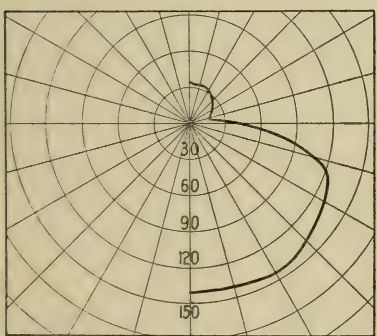

FIG. 7

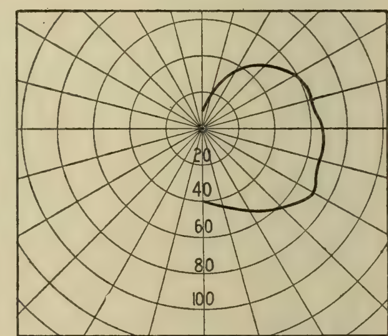

FIG. 8

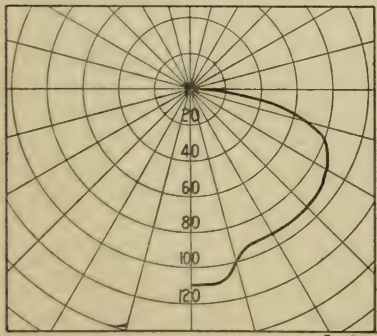

FIG. 9

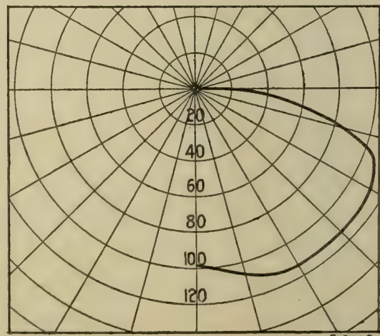

FIG. 10

Fig. 5.—Distribution curve of bare lamp.
Fig. 7.—Distribution curve of shade No. 2.
Fig. 9.—Distribution curve of shade No. 4.

Fig. 6.—Distribution curve of shade No. 1.
Fig. 8.—Distribution curve of shade No. 3.
Fig. 10.—Distribution curve of shade No. 5.

TABLE V.—COMPARISON OF BOX READINGS WITH POINT BY POINT METHOD.

Shade No.	1	2	3	4	5
Point by point	90.3	90.0	82.2	84.8	77.5
Box	90.0	88.6	84.5	78.1	70.2

It seems, therefore, that as long as the distribution is fairly uniform and no absorbing surfaces are introduced, the arrangement is fairly satisfactory. When the flux is all in one hemisphere and a dark surface is present, as in the case of the green shades, a considerable error is introduced. Some preliminary readings seemed to indicate slightly better results with the large screen. That was accordingly used for the remaining experiments.

With the large screen only a few readings were taken with the diffusing shades, the results being very nearly the same as with the small screen and therefore for present purposes considered satisfactory. An effort was made to find a condition under which the opaque shade No. 4 would give satisfactory results. None was found, although the result obtained with the source near the top of the box was an improvement over that taken at the center.

To determine the effect of lack of symmetry about the vertical axis in the distribution curve of the source, observations were made with the lamp in a horizontal position and set at different angles about a vertical axis, readings being taken every 15°. At 0° the side of the lamp was towards the side containing the window, at 90° the tip. Table VI gives the result.

TABLE VI.—EFFECT OF ASYMMETRY.

Position degrees	0	15	30	45	60	75	90
Readings at center	35.4	35.5	36.1	36.3	37.7	38.1	38.7
Readings at top	39.4	39.8	39.5	40.1	40.0	40.6	40.9

The asymmetry in this case is probably at least of the order of magnitude encountered in the concentrated filament lamps. The effect of asymmetry seems to be decreased by placing the source eccentrically. The validity of this result probably depends to some extent on the nature of the asymmetry.

It may be interesting in this connection to mention some readings that were taken on the distribution of intensity on the walls of the box. These were taken through the window by means of

a Macbeth illuminometer. With the bare lamp suspended 6 in. (15.2 cm.) from the top of the box, the readings on the top, the middle of the side, and the bottom were 15.5, 10.7 and 10.6 respectively. With shade No. 4 the corresponding readings were 6.8, 10.5 and 9.0.

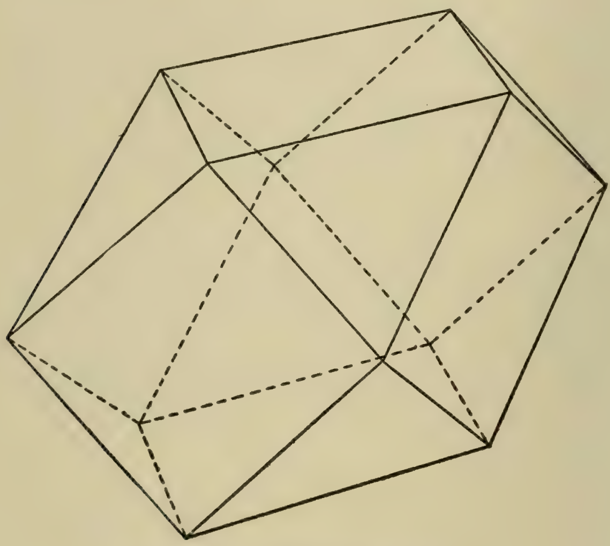

Fig. 11.—Cube with corners eliminated.

Cube with Corners Eliminated.—Finally a few readings were taken with a box 26 in. (66 cm.) cube, the corners of which had been eliminated as in the previous case. The shape of this box is shown in Fig. 11. The results obtained with shade No. 4 were the same as in the previous case. In order to see how much of this error was due to the absorbing surface, the outside of the shade was painted with lithopone. The readings obtained after this change gave an efficiency of 82.8 per cent. which is in fair agreement with the point by point method, although still a little low. It is probable that this error due to absorption is no larger than in a sphere of the same size. As this error decreases as the dimensions of the box increase, the box should be built considerably larger. In order to make sure that the effect of absorption was real, shade No. 5 was also given a coat of lithopone on the outside and its efficiency increased to 75.3 per cent.

CONCLUSIONS.

It seems fair to say that no integrating photometer of this type is an instrument of high precision.

For sources of similar distribution a rectangular box may be substituted for the sphere.

A cubical box with the corners eliminated as described is, for practical purposes, a satisfactory substitute for a sphere even for dissimilar and asymmetric sources.

ACKNOWLEDGEMENT.

I take pleasure in acknowledging my indebtedness to Mr. Paul McCorkle, who obtained a great number of the readings given in the paper.

BIBLIOGRAPHY.

BLOCH, L.
Kugelphotometer in Theorie und Praxis.
Electrotech. Zeit., vol. 26, pp. 1047 and 1074, 1905.
Kugelphotometer in Theorie und Praxis.
Electrotech. Zeit., vol. 27, p. 63, 1906.

CORSEPIUS, M.
Kugelphotometer von Ulbricht.
Electrotech. Zeit., vol. 27, p. 468, 1906.

MONASCH, B.
Kugelphotometer von Ulbricht.
Electrotech. Zeit., vol. 27, pp. 669 and 695, 1906.

ULBRICHT, R.
Die Bestimmung der mittleren räumlichen Lichtintensität.
Electrotech. Zeit., vol. 21, p. 595, 1900.
Die Bestimmung der mittleren räumlichen Lichtintensität.
Electrotech. Zeit., vol. 26, p. 1184, 1905.
Vorgänge in Kugelphotometer.
Electrotech. Zeit., vol. 26, p. 512, 1905.
Kugelphotometer in Theorie und Praxis.
Electrotech. Zeit., vol. 27, p. 52, 1906.
Die Hemisphärischen Lichtintensitat und das Kugelphotometer.
Electrotech. Zeit., vol. 27, p. 50, 1906.
Zur Anwendung des Kugelphotometers.
Electrotech. Zeit., vol. 28, p. 777, 1907.

WILD, R.
The Box Photometer.
Illum. Eng., London, vol. 3, p. 459, 1910.

AN INTERLABORATORY PHOTOMETRIC COMPARISON OF GLASS SCREENS AND OF TUNGSTEN LAMPS, INVOLVING COLOR DIFFERENCES.*

BY G. W. MIDDLEKAUFF AND J. F. SKOGLAND.

Synopsis: A report is given of a comparison of interlaboratory photometric measurements involving a considerable difference in color. The results are of value in showing the agreement which is to be expected between the results of groups of experienced observers working by different methods and with different kinds of photometers. The characteristics of those engaged in photometric work at the Bureau of Standards are discussed, and there is obtained additional evidence of the accuracy of the values assigned to the Bureau's 1.5-wpc. tungsten standards, which had previously been verified in an intercomparison with the National Physical Laboratory of England.

Contents:

I. INTRODUCTION.

Since the establishment of the International Candle in 1909, this unit has been maintained at the Bureau of Standards solely by means of a group of 4-wpc. carbon filament incandescent lamps. With the advent of the tungsten lamp there was introduced into standardization work the difficulty of comparing lights of different colors, and at once it became desirable to have the unit well established also in tungsten lamps operated at or near their normal color.

In 1911, by common agreement between the National Physical Laboratory of England and the Bureau of Standards, each laboratory prepared a group of tungsten standards calibrated for

*A paper read at the mid-Winter convention of the Illuminating Engineering Society New York, February 10, 11, 1916.

voltage corresponding to approximately 1.5 wpc. These two groups of lamps, which were thus operated at very approximately the same color, were then exchanged and each group was remeasured by the receiving laboratory at the voltage determined by the sending laboratory. A group, similar to the one sent to England, and standardized in the same series of measurements, was retained at the Bureau, and half of the group received from England, after measurement, were returned for remeasurement.

In view of the difficulties involved in the intercomparison, the result was very satisfactory as it showed that the two laboratories were in agreement to within the indicated precision of the measurements. In both laboratories the new standards were measured by means of Lummer-Brodhun contrast photometers of the standard type, and in terms of similar groups of 4-wpc. carbon standards, the English laboratory having made the comparison by the cascade method,[1] the Bureau of Standards by the use of two calibrated blue glass screens, each of which produced a color match between the two groups of standards compared.

It is obvious therefore that the calibration of the glass screens used by the Bureau in this intercomparison was a matter of prime importance, and for this reason a large amount of work has been done in checking, by various methods, the values first assigned.

In connection with these check measurements and after a determination of the candlepower and current of a group of tungsten sub-standards at several voltages had been made, and this followed by a further investigation of other groups of tungsten lamps, the voltage-current-candlepower curves were determined and accurately expressed by means of equations.[2] It was found that by employing these equations it is possible to measure tungsten lamps in color match with 4-wpc. carbon standards and compute with accuracy their value at any other color within the range investigated. In this way, as well as by direct comparisons, the new tungsten standards have been rechecked a number of times by different groups of observers.

[1] Paterson and Dudding, *Proc. Phys. Soc. London*, April 15, 1915, p. 263; also *Phil. Mag.*, July, 1915, p. 63.

[2] Middlekauff and Skogland, Characteristics Equations of Tungsten Filament Lamps and their Application in Heterochromatic Photometry, TRANS. I. E. S., vol. IX, p. 734, 1914; also *Bulletin* Bureau of Standards, vol. XI, p. 483.

These equations have an important application also in the life testing of tungsten lamps, because in some testing laboratories it is customary to photometer the lamps at or near rated voltage and compute the voltage corresponding to the efficiency at which it is desired to burn the lamps on life test.

In the establishment of the 1.5-wpc. tungsten standards and also in the determination of the characteristic equations, the photometric measurements of necessity involved color differences. Although numerous check measurements have been made and the results have been very satisfactory, it is, of course, realized that if some other group of observers had made these measurements the values obtained might have been different.

It was therefore suggested that an interlaboratory photometric comparison of lights involving color differences such as those encountered in these measurements would yield valuable information not only as to the agreement which might be reasonably expected among different groups of experienced observers, but also information as to the merits of different methods of making such measurements.

II. LABORATORIES CO-OPERATING.

The Bureau therefore, in May, 1914, invited several of the more important photometric laboratories of the country to co-operate with it in making measurements of this kind.

Through Dr. E. P. Hyde, Dr. C. H. Sharp, and Dr. H. E. Ives, respectively, the Nela Research Laboratory, the Electrical Testing Laboratories, and the Physical Laboratory of the United Gas Improvement Company, kindly agreed to make such measurements on glass screens and tungsten lamps as the Bureau would direct.

III. SCREENS, LAMPS, AND INSTRUCTIONS AS TO METHODS OF MEASUREMENT.

For this intercomparison there were selected three blue glass screens of different color densities and marked 2B, 2½B and 3B, respectively. 2½B was of approximately the same color density as the screens used by the Bureau in the intercomparison with England, and was therefore such as to produce a color match between the 4-wpc. carbon standards and the 1.5-wpc. tungsten standards. 2B and 3B were of lesser and greater color density,

respectively, than 2½B, producing a color match between the 4-wpc. carbon standards and tungsten lamps at about 1.9 wpc. and 1.25 wpc. respectively.

The transmission of each glass for light of 4-wpc. carbon color was to be determined by each laboratory, and, in order that the proper color might be used, a carbon standard of this color at a specified voltage was sent along with the screens.

There were selected also four tungsten standards to be measured for candlepower and current at several specified voltages, the color at the lowest voltage being the same as that of the 4-wpc. carbon standards. The candlepower of the other voltages was to be determined in terms of the value at the lowest voltage taken as standard, or unity.

The voltages specified for these measurements corresponded to a range of from 3.1 wpc. to 0.85 wpc. for the tungsten lamp. The lamps were selected from those used in the investigation of the characteristic curves and included a 60-watt sintered filament lamp (No. 2608); a 60-watt "formed" drawn-wire lamp (No. 2662) with spring anchors; and two 40-watt drawn-wire lamps (Nos. 2865 and 2866).

As the purpose of the investigation was to obtain information as to methods and the agreement of different groups of observers in passing from one color to another in photometric measurements, no instructions other than those mentioned above were issued to the laboratories. It was desired that each laboratory proceed by the method it considered best, and it was not expected that a large number of measurements would be made. Hence, in view of the difficulties which were to be met in these measurements, it was hardly to be expected that values established by the Bureau as the result of a much larger number of measurements and checks would be repeated exactly. However, as will appear later, the results of all the laboratories are extremely consistent and the agreement quite satisfactory.

Two of the laboratories (E. T. L. and N. R. L.) used the standard type Lummer-Brodhun contrast photometer in all the measurements. The third laboratory, U. G. I., in the measurements on the screens, used a special flicker photometer,[3] and in

[3] Ives, H. E., *Phys. Rev.*, Sept. 1914, p. 222.

the measurements on the lamps a Lummer-Brodhun photometer having the eye-piece a cell containing a Crova[4] solution which was calibrated by a method involving the flicker photometer. All the measurements by the U. G. I. were made under selected conditions of illumination and with groups of observers selected after tests of their color vision with respect to the average of much larger groups. The data obtained are therefore valuable in making a comparison, not only of observers but also of different methods of measurement.

In no laboratory were the lamps measured at the same time as the screens, a period of from four to thirteen months having intervened between the two series.[5] Although this was not intentional, it fortunately proved of value in showing that each laboratory consistently maintained its criterion in measurements involving a color difference. In order to avoid confusion, all the results, including those of the Bureau, on the screens are given together, as are likewise all the results on the lamps.

IV. RESULTS ON THE SCREENS.

The values for the screens are given in the four following tables, and, except as noted, they are as stated in the reports from the laboratories. The results of those using the Lummer-Brodhun photometer are grouped together, and when comparisons are made, flicker values are compared with the mean of those obtained with the Lummer-Brodhun.

TABLE I.—BUREAU OF STANDARDS.

	Transmission					
	2 B		2½ B		3 B	
Observers	Indirect method	Direct method	Indirect method	Direct method	Indirect method	Direct method
G. W. M.	0.652	0.654	0.585	0.588	0.537	0.542
J. F. S.	0.651	0.652	0.585	0.584	0.538	0.538
B. M.	0.648	0.645	0.581	0.575	0.541	0.526
H. B. S.	0.652	0.667	—*	0.596	—*	0.552
W. J. K.	0.652	0.652	0.585	0.580	0.539	0.534
W. H. V.	0.651	0.648	0.581	0.581	0.535	0.535
A. H. T.	0.651	0.655	0.584	0.583	0.541	0.535
G. J. S.	0.650	0.652	0.585	0.582	0.538	0.536
Means	0.651	0.653	0.584	0.584	0.538	0.537

*Observer not available.

[4] Ives and Kingsbury; TRANS. I. E. S., 10, p. 716, 1915.

[5] The intercomparison was begun in June, 1914, but was not completed until in December, 1915.

Photometer used: Standard Lummer-Brodhun contrast. Approximate illumination on the photometer screen; 10 meter-candles.

Methods: 1. Direct Method.—Settings were first made with a tungsten test lamp at 4-wpc. carbon color and the comparison lamp set to a color match, with the screen on the test side. The screen was then removed and for it was substituted a rotating sectored disk having a percentage opening approximately equal to the transmission of the screen. The ratio of the settings with screen in to those with screen out gave the transmission.

2. Indirect Method.—The first settings were made as in the direct method. The screen was then removed and the test lamp was increased in voltage to match the comparison lamp in color. The ratio of the candlepower of the test lamp at these two voltages was computed by means of the voltage-candlepower equation. With this factor applied, the ratio of the settings, screen in to screen out, gave the transmission.

Each value in the above table represents the mean of about four independent determinations, the average deviation by either method being about 0.5 per cent.

TABLE II.—ELECTRICAL TESTING LABORATORIES.

	Transmission								
	2 B			2½ B			3 B		
Observers	Series 1	Series 2	Weighted mean	Series 1	Series 2	Weighted mean	Series 1	Series 2	Weighted mean
C.H.S.	0.651	—	0.651	0.583	—	0.583	0.537	—	0.537
W.F.L.	0.660	0.672	0.666	0.594	0.586	0.590	0.530	0.553	0.542
M.H.T.	0.660	0.662	0.661	0.585	0.588	0.586	0.545	0.546	0.545
C.E.H.	0.656	0.652	0.655	0.586	0.587	0.586	0.545	0.537	0.542
W.A.M.	0.656	0.657	0.656	0.587	0.576	0.583	0.543	0.539	0.542
Z.N.C.	0.653	—	0.653	0.579	—	0.579	0.535	—	0.535
A.K.	0.659	—	0.659	0.589	—	0.589	0.539	—	0.539
E.H.	—	0.666	0.666	—	0.594	0.594	—	0.555	0.555
Means	0.656	0.662	—	0.586	0.586	—	0.539	0.546	—
Weighted means	0.656	0.659	0.657	0.585	0.586	0.585	0.541	0.543	0.542

Photometer used: Standard Lummer-Brodhun contrast. Approximate illumination on the photometer screen: 2.5 to 3.8 meter-candles. As the distance between test and comparison lamps was fixed, the illumination depended upon the screen used and was highest with the screen removed.

Method: Two carbon lamps, each operated at a voltage giving

a match in color with the B. S. 4-wpc. carbon lamp, were set up at opposite ends of the photometer. Settings were made, first without the screen, then with the screen interposed. This was done first on one side of the photometer and then on the other. The observers were weighted according to their experience in color difference measurements and the number of measurements made in these tests. Series 1 and 2 are independent determinations by this method. For purposes of comparison the weighted mean values (columns 4, 7, and 10) for each observer were computed by the authors.

TABLE III.—Nela Research Laboratory.

	Transmission								
	2 B			2½ B			3 B		
Observers	Series 1	Series 2	Mean	Series 1	Series 2	Mean	Series 1	Series 2	Mean
E.P.H.	0.660	0.662	0.661	0.590	0.592	0.591	0.544	0.543	0.544
F.E.C.	0.659	0.661	0.660	0.592	0.590	0.591	0.548	0.546	0.547
M.L.	0.665	0.660	0.662	0.593	0.590	0.592	0.551	0.541	0.546
C.F.S.	0.652	0.650	0.651	0.578	0.578	0.578	0.531	0.530	0.531
R.G.B.	0.664	0.662	0.663	0.594	0.592	0.593	0.550	0.549	0.550
I.R.W.	0.656	0.656	0.656	0.584	0.584	0.584	0.540	0.538	0.539
Means	0.659	0.658_5	0.659	0.588_5	0.588	0.588	0.544	0.543	0.543

Photometer used: Standard Lummer-Brodhun contrast. Approximate illumination on photometer screen: 17 meter-candles.

Method: Same as the B. S. direct method, except that the screen and sectored disk were employed on the side of the comparison lamp, which was set to 4-wpc. carbon color. Series 1 and 2 are independent determinations by this method.

TABLE IV.—United Gas Improvement Company.

	Transmission								
	2 B			2½ B			3 B		
Observers	Series 1	Series 2	Mean	Series 1	Series 2	Mean	Series 1	Series 2	Mean
H.E.I.	0.645	0.650	0.6475	0.580	0.579	0.5795	0.534	0.527	0.5305
E.F.K ...	0.658	0.661	0.6595	0.587	0.588	0.5875	0.548	0.543	0.5455
F.A.S. ...	0.645	0.646	0.6455	0.583	0.577	0.5800	0.528	0.523	0.5255
B.J.	0.656	0.642	0.6490	0.575	0.574	0.5745	0.528	0.528	0.5280
D.V.L.D.	0.639	0.642	0.6405	0.585	0.578	0.5815	0.529	0.522	0.5255
E.J.B. ...	0.637	0.639	0.6380	0.572	0.573	0.5725	0.521	0.522	0.5215
W.M.W. .	0.640	0.643	0.6415	0.576	0.577	0.5765	0.521	0.528	0.5245
Means ...	0.646	0.646	0.646	0.580	0.578	0.579	0.530	0.528	0.529

Photometer used: Special flicker. (See footnote 3.) Brightness of photometer field: That of a magnesium oxide surface under 25 meter-candles illumination.

Method: Direct.—The measurements were made by 7 observers so selected from 25 that their mean on the color difference for which they were tested was the same as that of the 25.

TABLE V.—DEVIATIONS OF EACH OBSERVER FROM THE MEAN OF HIS LABORATORY.

BUREAU OF STANDARDS.

(Direct Method)

Observers	Transmission 2B	2½B	3B	Mean	Deviation of observers from mean of all 2B	2½B	3B	Mean of devs.	Max. dif. between devs.
G.W.M.	0.654	0.588	0.542	0.595	+0.001	+0.004	+0.005	0.003	0.004
J.F.S.	0.652	0.584	0.538	0.592	—0.001	0.000	+0.001	0.001	0.002
B.M.	0.645	0.575	0.526	0.582	—0.008	—0.009	—0.011	0.009	0.003
H.B.S.	0.667	0.596	0.552	0.605	+0.014	+0.012	+0.015	0.014	0.003
W.J.K.	0.652	0.580	0.534	0.589	—0.001	—0.004	—0.003	0.003	0.003
W.H.V.	0.648	0.581	0.535	0.588	—0.005	—0.003	—0.002	0.003	0.003
A.H.T.	0.655	0.583	0.535	0.591	+0.002	—0.001	—0.002	0.002	0.004
G.J.S.	0.652	0.582	0.536	0.590	—0.001	—0.002	—0.001	0.001	0.001
Means	0.653	0.584	0.537	0.591	0.004	0.004	0.005	0.004	0.003

(Indirect Method)

Observers	2B	2½B	3B	Mean	2B	2½B	3B	Mean of devs.	Max. dif. between devs.
G.W.M.	0.652	0.585	0.537	0.591	+0.001	+0.001	—0.001	0.001	0.002
J.F.S.	0.651	0.585	0.538	0.591	0.000	+0.001	0.000	0.000	0.001
B.M.	0.648	0.581	0.541	0.590	—0.003	—0.003	+0.003	0.003	0.006
H.B.S.	0.652	—	—	—	+0.001	—	—	—	—
W.J.K.	0.652	0.585	0.539	0.592	+0.001	+0.001	+0.001	0.001	0.000
W.H.V.	0.651	0.581	0.535	0.589	0.000	—0.003	—0.003	0.002	0.003
A.H.T.	0.651	0.584	0.541	0.592	0.000	0.000	+0.003	0.001	0.003
G.J.S.	0.650	0.585	0.538	0.591	—0.001	+0.001	0.000	0.001	0.002
Means	0.651	0.584	0.538	0.591	0.001	0.001	0.002	0.001	0.002

ELECTRICAL TESTING LABORATORIES.

(Direct Method)

Observers	2B	2½B	3B	Mean	2B	2½B	3B	Mean of devs.	Max. dif. between devs.
C.H.S.	0.651	0.583	0.537	0.590	—0.006	—0.002	—0.005	0.004	0.004
W.F.L.	0.666	0.590	0.542	0.599	+0.009	+0.005	0.000	0.005	0.009
M.H.T.	0.661	0.586	0.545	0.597	+0.004	+0.001	+0.003	0.003	0.003
C.E.H.	0.655	0.586	0.542	0.594	—0.002	+0.001	0.000	0.001	0.003
W.A.M.	0.656	0.583	0.542	0.594	—0.001	—0.002	0.000	0.001	0.002
Z.N.C.	0.653	0.579	0.535	0.589	—0.004	—0.006	—0.007	0.006	0.003
A.K.	0.659	0.589	0.539	0.596	+0.002	+0.004	—0.003	0.003	0.007
E.H.	0.666	0.594	0.555	0.605	+0.009	+0.009	+0.013	0.010	0.004
Means	0.657	0.585	0.542	0.595	0.005	0.004	0.004	0.004	0.004

TABLE V.—(*Continued.*)

NELA RESEARCH LABORATORY.

(Direct Method)

E.P.H ...	0.661	0.591	0.544	0.599	+0.002	+0.003	+0.001	0.002	0.002
F.E.C. ..	0.660	0.591	0.547	0.599	+0.001	+0.003	+0.004	0.003	0.003
M.L......	0.662	0.592	0.546	0.600	+0.003	+0.004	+0.003	0.003	0.001
C.F.S	0.651	0.578	0.531	0.587	—0.008	—0.010	—0.012	0.010	0.004
R.G.B....	0.663	0.593	0.550	0.602	+0.004	+0.005	+0.007	0.005	0.003
I.R.W....	0.656	0.584	0.539	0.593	—0.003	—0.004	—0.004	0.004	0.001
Means ...	0.659	0.588	0.543	0.597	0.003	0.005	0.005	0.004	0.002

UNITED GAS IMPROVEMENT. CO.

(Direct Method.)

H.E.I. ...	0.648	0.580	0.530	0.586	+0.002	+0.001	+0.001	0.001	0.001
E.F.K....	0.660	0.588	0.546	0.598	+0.014	+0.009	+0.017	0.013	0.008
F.A.S. ...	0.646	0.580	0.526	0.584	0.000	+0.001	—0.003	0.001	0.004
B.J.......	0.649	0.574	0.528	0.584	+0.003	—0.005	—0.001	0.003	0.008
D.V.L. D.	0.640	0.582	0.526	0.583	—0.006	+0.003	—0.003	0.004	0.009
E.J.B. ...	0.638	0.572	0.521	0.577	—0.008	—0.007	—0.008	0.008	0.001
W.M.W. .	0.642	0.576	0.524	0.581	—0.004	—0.003	—0.005	0.004	0.002
Means ...	0.646	0.579	0.529	0.585	0.005	0.004	0.005	0.005	0.005

a. Comparison of Individuals' Values.—Another statement of the results, including only the mean of the values obtained by each observer on each of the three screens, is given in Table V. In the 5th column is given the mean of the values of each observer for the three glasses. In the 6th, 7th, and 8th columns are the deviations of each observer's value from the mean of the laboratory on each glass. The constancy of the ratio of an observer's determination to that of his laboratory shows the consistency with which he maintains his criterion throughout the range of color included. An examination of the deviations shown in this table (excluding for the present those of the Bureau by the indirect method) shows that practically every observer, irrespective of the kind of photometer used, maintained a fairly definite relation to the mean of the observers of his laboratory. An observer's agreement with himself is indicated by the differences given in the last column of the table.

By the indirect method, the variations among observers is avoided, the difficulties of measurements with a color difference having been previously met in the determination of the character-

istic equation. As shown by the table, the deviations of all observers are about equal and about one-fourth what they are by the direct (color difference) method, although there is practically the same degree of agreement of an observer with himself. The chief advantage of this method in calibrating a screen is that a reliable result may be obtained by any group of observers, while by the direct method the results may be somewhat different depending upon the characteristics of the observers.

b. Comparison of Laboratories' Values.—In order to show in the same way the agreement among the various laboratories, each taken as a unit, the final means for each laboratory are given in Table VI in which, as before, the flicker values are compared with the mean of those obtained with the Lummer-Brodhun photometer.

TABLE VI.—DEVIATIONS OF LABORATORIES' VALUES FROM THE MEAN OF THOSE USING THE LUMMER-BRODHUN PHOTOMETER.

	Transmission				Deviations from mean L-B values				Max. dif. between
Laboratory	2B	2½B	3B	Mean	2B	2½B	3B	Mean	devs.
B.S.	0.653	0.584	0.537	0.591	—0.003	—0.002	—0.004	0.003	0.002
E.T.L. ..	0.657	0.585	0.542	0.595	+0.001	- 0.001	+0.001	0.001	0.002
N.R.L....	0.659	0.588	0.543	0.597	+0.003	+0.002	+0.002	0.002	0.001
Means ...	0.656	0.586	0.541	0.594	0.002	0.002	0.002	0.002	0.002
U.G.I. ...	0.646	0.579	0.529	0.585	—0.010	—0.007	—0.012	0.010	0.005

V. RESULTS ON THE LAMPS.

The results on the lamps were expressed differently by each laboratory. One (E. T. L.) gave all the values in candlepower; another (U. G. I.) reported the values as ratios using the value at the lowest voltage as unity; and the third (N. R. L.) gave the ratio of the candlepower at each voltage to the candlepower at the next lower voltage. Only one laboratory (N. R. L.) reported the values of the individual observers as was done by all in their reports on the screens. For this reason only the mean values obtained by each laboratory are given in the table of results (Table VII). The Bureau's values of both current and candlepower were read from the characteristic curves previously determined by a group of observers whose mean was practically the same as the mean of the group that made the measurements on the screens.

In the Electrical Testing Laboratories the candlepower measurements were made by two observers whose mean was the same as the mean of observers on the screens and the color steps were made with Wratten filters which had been calibrated by a large number of observers. In the Nela Research Laboratory the measurements on the lamps and screens were made by the same group of observers with the exception that observer M. L. made no measurements on the lamps. The cascade method was used in determining values on the lamps at the various voltages.

In the U. G. I. Laboratory the lamps were measured with a Lummer-Brodhun photometer having in the eye-piece a Crova solution calibrated on the photometric scale there used in which are involved the flicker photometer under certain chosen illumination and other conditions and the selection of observers from a large group. The group used as a basis for the Crova solution work consisted of sixty-one observers; the glass screen calibrations were on the basis of a group of twenty-five.

TABLE VII.—CANDLEPOWER AND CURRENT VALUES FOUND BY THE DIFFERENT LABORATORIES.

Lamp No.	Volts	Relative candlepower				Amperes			
		B.S.	E.T.L.	N.R.L.	U.G.I.	B.S.	E.T.L.	N.R.L.	U.G.I.
2608......	71	1.000	1.000	1.000	1.00	0.3646	0.3647	0.3646	0.3650
	81	1.674	1.677	1.684	1.68	0.3944	0.3944	0.3944	0.3951
	91	2.604	2.616	2.627	2.60	0.4224	0.4229	0.4226	0.4234
	101	3.832	3.848	3.864	3.85	0.4495	0.4498	0.4496	0.4500
	111	5.392	5.434	5.460	5.34	0.4753	0.4758	0.4756	0.4757
2662......	70	1.000	1.000	1.000	1.00	0.3926	0.3925	0.3920	0.3929
	80	1.687	1.695	1.696	1.69	0.4245	0.4249	0.4244	0.4253
	90	2.638	2.647	2.661	2.60	0.4549	0.4555	0.4551	0.4555
	100	3.896	3.923	3.931	3.88	0.4843	0.4846	0.4840	0.4844
	110	5.501	5.554	5.585	5.45	0.5118	0.5125	0.5120	0.5121
2865......	72	1.000	1.000	1.000	1.00	0.2625	0.2628	0.2626	0.2625
	82	1.659	1.659	1.674	1.65	0.2838	0.2841	0.2838	0.2840
	92	2.567	2.579	2.615	2.56	0.3037	0.3041	0.3036	0.3035
	112	5.277	5.354	5.389	5.28	0.3408	0.3411	0.3406	0.3408
	132	9.40	9.45	9.58	9.22	0.3744	0.3752	0.3748	0.3749
2866......	72	1.000	1.000	1.000	1.00	0.2611	0.2615	0.2614	0.2616
	92	2.576	2.588	2.621	2.58	0.3020	0.3024	0.3024	0.3024
	112	5.304	5.355	5.415	5.30	0.3390	0.3395	0.3393	0.3394
	122	7.191	7.223	7.321	7.16	0.3562	0.3568	0.3566	0.3566
	132	9.46	9.52	9.63	9.38	0.3728	0.3735	0.3732	0.3731

The Nela Research Laboratory gave the highest and lowest ampere values at each voltage, but to make the results uniform with the definite values reported by the other laboratories the mean of these extremes at each voltage was assumed as the correct ampere value. The deviations of the ampere values as given for the various laboratories in Table VII from the mean of all at each voltage have been computed and found to be, on the average, about 0.05 per cent. and the same for all four lamps.

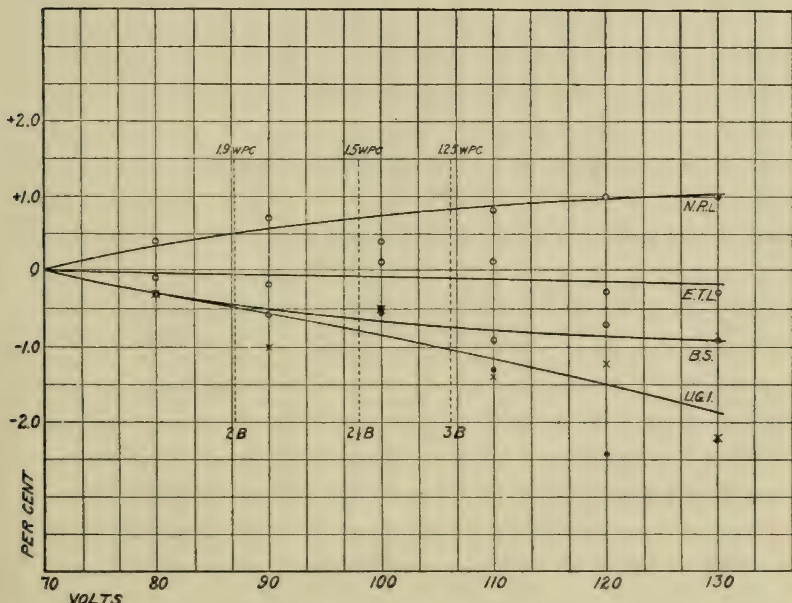

Fig. 1.—Values on the lamps expressed as differences from the mean obtained by three laboratories with the Lummer-Brodhun photometer. The dots represent flicker values found by Crittenden and Richtmyer.

In Table VIII are given the values of the ratios of the candlepower at each voltage to that at the lowest voltage, which corresponds to 4-wpc. carbon color. The laboratories are arranged in the order in which they measured the lamps. As in the case of the results on the glass screens, the values obtained by each laboratory are compared with the mean of the three laboratories using the Lummer-Brodhun photometer.

TABLE VIII.—COMPARISON OF CANDLEPOWER RATIOS FOUND BY THE DIFFERENT LABORATORIES.

Lamp No.	Voltage ratio	Candlepower ratio B.S.	E.T.L.	N.R.L.	Means	U.G.I.
2608	81:71	1.674	1.677	1.684	1.678	1.68
2662	80:70	1.687	1.695	1.696	1.693	1.69
2865	82:72	1.659	1.659	1.674	1.664	1.65
Means		1.673	1.677	1.685	1.678	1.673
Dev. from mean		—0.3%	—0.1%	+0.4%	0.3%	—0.3%
2608	91:71	2.604	2.616	2.627	2.616	2.60
2662	90:70	2.638	2.647	2.661	2.649	2.60
2865	92:72	2.567	2.579	2.615	2.587	2.56
2866	92:72	2.576	2.588	2.621	2.595	2.58
Means		2.596	2.608	2.631	2.612	2.585
Dev. from mean		—0.6%	—0.2%	+0.7%	0.5%	—1.0%
2608	101:71	3.832	3.848	3.864	3.848	3.85
2662	100:70	3.896	3.923	3.931	3.917	3.88
Means		3.864	3.886	3.898	3.883	3.865
Dev. from mean		—0.5%	+0.1%	+0.4%	0.3%	—0.5%
2608	111:71	5.392	5.434	5.460	5.429	5.34
2662	110:70	5.501	5.554	5.585	5.547	5.45
2865	112:72	5.277	5.354	5.389	5.340	5.28
2866	112:72	5.304	5.355	5.415	5.358	5.30
Means		5.368	5.424	5.462	5.418	5.342
Dev. from mean		—0.9%	+0.1%	+0.8%	0.6%	—1.4%
2866	122:72	7.191	7.223	7.321	7.245	7.16
Dev. from mean		—0.7%	—0.3%	+1.0%	0.7%	—1.2%
2865	132:72	9.40	9.45	9.58	9.48	9.22
2866	132:72	9.46	9.52	9.63	9.54	9.38
Means		9.43	9.48	9.61	9.51	9.30
Dev. from mean		—0.9%	—0.3%	+1.0%	0.7%	—2.2%

In order to determine later the agreement of the measurements on the lamps with those on the screens, percentage deviations from the mean obtained for all lamps at each voltage are given in Fig. 1, and the representative curve for each laboratory is drawn. The points at which the screens fall (*i. e.*, the approximate voltage to which a tungsten test lamp would have to be set to obtain a color match with the screen removed) are indicated by the vertical dotted lines which intersect the curves of this figure. Correction to the mean value of the transmission of each screen may now

be assigned from a consideration of the percentage difference on the lamps as shown in the figure at the intersection with the corresponding vertical line. There is thus obtained for the screens a relation among the laboratories corresponding to that given by the curves for the lamps.

VI. COMPARISON OF RESULTS ON LAMPS AND SCREENS.

The values obtained for the glasses by direct measurement and those by computation (see Sec. V) from the results on the lamps are compared in Table IX. In the last four columns of the lower half of the table are the differences between these two sets of values. It is to be noted that for the three laboratories using the Lummer-Brodhun photometer the differences average about 0.2 per cent. on the mean of the three glasses. That is, each laboratory was remarkably consistent in the two series of measurements.

TABLE IX.—COMPARISON OF OBSERVED AND COMPUTED VALUES ON THE SCREENS.

	Value of screens as observed.				
Screens	B. S.	E. T. L	N. R. L.	Mean	U. G. I
2B	0.653	0.657	0.659	0.656	0.646
2½ B	0.584	0.585	0.588	0.586	0.579
3B	0.537	0.542	0.543	0.541	0.529
Means	0.591	0.595	0.597	0.594	0.585

	Relative values as computed from measurements on lamps.				Differences, computed values from observed values			
Screens	B. S.	E.T.L.	N.R.L	U.G.I.	B. S.	E.T.L.	N.R.L.	U.G.I.
2B	0.653	0.6555	0.6595	0.6525	0.000	+0.0015	—0.0005	—0.0065
2½ B	0.5825	0.5855	0.5905	0.5815	+0.0015	—0.0005	—0.0025	—0.0025
3B	0.537	0.5405	0.5455	0.5355	0.000	+0.0015	—0.0025	—0.0065
Means	0.591	0.594	0.5985	0.590	0.0005	0.0012	0.0018	0.0052

In regard to the flicker values, it appears that the somewhat greater differences between the results on the glasses and the lamps is due to the values assigned to the former. As further evidence of this fact, the results by Crittenden and Richtmyer[6] on two of the lamps (Nos. 2865 and 2866) agree very closely, except at 120 volts,[7] with those reported by the U. G. I., their

[6] Paper presented at mid-winter convention I. E. S., New York, February 10, 11, 1916.

[7] These authors state that this value should not be given equal weight with the others because only one lamp was measured at this voltage.

values being indicated by dots in Fig. 1. On the other hand the result given by the same authors for the screens by the flicker method do not agree so well with the U. G. I. values here reported.

The differences given in this table show that the first three laboratories mentioned are consistent in their measurements on the lamps and screens to within less than 0.2 per cent. on the average, and that the U. G. I. computed value is practically the same as that of the Bureau of Standards.

VII. ADDITIONAL CHECK MEASUREMENTS.

In order to secure a further check of the ratio of the values obtained by the Nela Research Laboratory and the Bureau of Standards, arrangements were made whereby Mr. F. E. Cady, through the courtesy of Dr. Hyde, came to the Bureau and made a number of comparative measurements with the Bureau's observers who took part in this intercomparison.

Comparative measurements were first made of the ratio Y/B and of the transmission of glass screen 3G using the flicker photometer (see next section). In these measurements the B. S. observers checked their former values to within the errors of measurements and hence their values in this test are not here given. Following this test, one of the lamps (No. 2661) used in establishing the voltage-candlepower curve for tungsten lamps was measured at 106 volts in terms of its value at 70 volts using a Lummer-Brodhun photometer. At the latter voltage the color of this lamp was the same as that of a 4-wpc. carbon and at the upper voltage the color corresponded to that produced by glass 3B when used with a 4-wpc. carbon lamp. The comparison lamp was adjusted for color match with No. 2661 at 70 volts and the illumination on the photometer screen was adjusted to 10 meter-candles, as in all previous measurements made at the Bureau in this intercomparison. Three series of determinations of the ratio of candlepower at the two voltages were made by five observers, including Mr. Cady and all settings were made by the contrast principle. These results, together with the values previously obtained for 3B by these five observers (see Table V), each in his own laboratory, are given in Table X.

A comparison of the last two columns shows that, for the lamp, the percentage difference between the value of Mr. Cady

and the mean of the B. S. observers is practically the same as for the screen although the latter was measured under somewhat different conditions of illumination in the two laboratories. As the color step was the same in each case, it can be reasonably concluded from this check that the indicated small difference between the two laboratories is real and is due, at least in a great measure, if not entirely, to a difference in the characteristics of the two groups of observers. In this connection it is of interest to note that if, in either laboratory, the first half of the observers, in the order given in Table V, be arbitrarily taken as one group and the other half as a second group, the difference between the value by the two groups in either laboratory is comparable with the difference between the laboratories themselves.

TABLE X.—COMPARISON OF CHECK MEASUREMENTS.

Observer	Series 1	Series 2	Series 3	Mean	Transmission of 3B form Table V
F. E. C.	4.90	4.92	4.91	4.91	0.547
G. W. M.	4.85	4.87	4.81	4.85	0.542
J. F. S.	4.79	4.84	4.81	4.81	0.538
W. J. K.	4.80	4.81	4.73	4.78	0.534
G. J. S.	4.80	4.76	4.73	4.77	0.536
Mean of B. S. obser.	4.81	4.82	4.77	4.80	0.537_5
Value from B. S. Voltage-candlepower Curve				4.81	0.538

It is important therefore that all measurements involving a color difference should be left as much as possible to the standardizing laboratory where the observers should be carefully selected, their relation to normal determined and, if necessary, corrections made to their observations.

VIII. CHARACTERISTICS OF THE BUREAU OF STANDARDS' OBSERVERS.

In the investigation by Crittenden and Richtmyer, the observers who took part in this intercomparison determined, with the flicker photometer, a value for the ratio of the Ives-Kingsbury yellow and blue solutions[8] and also a value for the transmission of glass screen 3G. These values, together with the values obtained with the Lummer-Brodhun photometer for glass screen 3B (Table V,

[8] TRANS. I. E. S., vol. X. p. 203, 1915.

direct method) which has about the same color density as 3G, are given in Table XI. In this table are included also the values by Mr. Cady and those by Dr. C. H. Sharp and Dr. H. E. Ives, who visited the Bureau and made these measurements during the progress of the above investigation by Crittenden and Richtmyer.

TABLE XI.—DATA ON OBSERVERS.

Observers	Ratio Y/B	Transmission 3G flicker phot.	Transmission 3B L-B phot.	Deviations from mean of 114 observers Flicker phot.	Deviations from mean of 114 observers L-B phot.	Difference between deviations
G. W. M......	1.025	0.540	0.542	—0.003	+0.008	+0.011
J. F. S.	1.103	0.534	0.538	—0.009	+0.004	+0.013
B. M..........	1.120	0.532	0.526	—0.011	—0.008	+0.003
H. B. S.	0.822	0.559	0.552	+0.016	+0.018	+0.002
W. J. K.......	0.968	0.540	0.534	—0.003	0.000	+0.003
W. H. V.	0.948	0.548	0.535	+0.005	+0.001	—0.004
A. H. T.	1.014	0.542	0.535	—0.001	+0.001	+0.002
G. J. S..	0.998	0.540	0.536	—0.003	+0.002	+0.005
Means	1.000	0.542	0.537	—0.001	+0.003	+0.004
F. E. C.	1.044	0.536	0.547	—0.007	+0.013	+0.020
C. H. S.	1.058	0.534	0.537	—0.009	+0.003	+0.012
H. E. I.	0.951	0.542	0.540	—0.001	+0.006	+0.007
Average of 114 observers ...	0.99	0.543	0.534	—	—	—

It is to be noted that although there is considerable variation in the ratio Y/B among the different individuals in the Bureau's group of eight observers, the mean of all is remarkably close to the characteristic ratio (0.99) found by Crittenden and Richtmyer for the average eye of 114 observers. Hence, as is evident from the results on 3G a mean value obtained by this group with the flicker photometer, under the conditions used by these investigators, would require practically no correction to obtain a value corresponding to that for the average eye.

A comparison of the values on 3B shows that this group is very close to the average eye also in its results with the Lummer-Brodhun photometer, although not quite so close as with the flicker. Whether this slightly greater variation arises from the fact that in the average-eye work of Crittenden and Richtmyer the illumination was higher than in this investigation, or that in the former the photometer was used as an equality rather than as a

contrast field, or from the greater uncertainty of the Lummer-Brodhun photometer, is difficult to say. However, as is shown by the differences between deviations and better by means of a curve between values of Y/B and transmission, all the individuals of this group do not have, with respect to the mean of the 114, the same relation with the Lummer-Brodhun photometer as they do with the flicker, the first two being decidedly different by the two methods.

Now it is found that if these two observers be omitted, the mean of the other six, by the flicker test, is just as close to normal as the whole group, their mean values for 3G and Y/B being 0.5435 and 0.98, respectively; and further, their mean value for 3B is more nearly equal to the average eye value (0.534), being 0.536 instead of 0.537 as found by the whole group. It would appear, therefore, that in order to make a comparison of present with former values, as is done later below, there is some advantage in using the mean of this "selected" group of six.

Further checks on the value of 3B from the present investigation as well as from the investigation of Crittenden and Richtmyer, who determined values for 3G which was found to be 1.6 per cent. higher than 3B, are given in the following table. The 20 observers selected by Crittenden and Richtmyer from the 114 had considerable photometric experience and were well distributed with respect to the average eye characteristic as determined with the flicker photometer.

IX. CHECKS OF FORMER VALUES.

Screen 2½B was chosen for this intercomparison because it had approximately the same color value as the glasses used in the intercomparison with the National Physical Laboratory. The mean values found for this screen by the group of eight and by the group of six were 0.5836 and 0.5828, respectively. The relative value of 2½B to 3½C which is one of the glasses used in the B. S.-N. P. L. intercomparison, has been recently determined and found to be as follows:

	3½ C	= 2½ B + 0.010
Therefore, by the group of 8	"	= 0.5836 + 0.010 = 0.5936
and by the group of 6	"	= 0.5828 + 0.010 = 0.5928
Value used in the B.S.-N.P.L. intercomparison		= 0.5924

I. With the Lummer-Brodhun photometer:
  A. As found by Crittenden and Richtmyer:
    1. By 114 observers selected at random from the Bureau of Standards scientific staff (one set each) .... 3B = 0.534
    2. By 20 observers selected from the 114 (two sets each) .... 3B = 0.536
    3. By 14 most consistent observers selected from the 20 (two sets each)........... 3B = 0.538
  B. As found in this intercomparison:
    1. By 8 observers .... 3B = 0.537
    2. By 6 observers selected from the 8....... 3B = 0.536
II. With the flicker photometer:
  A. As found by Crittenden and Richtmyer:
    1. By 114 observers (same as above)....... 3B = 0.534
    2. By 20 observers (same as above)....... 3B = 0.534
    3. By 14 observers (same as above)....... 3B = 0.534
    4. By 8 observers (same as above)....... 3B = 0.533
    5. By 6 observers (same as above)....... 3B = 0.534
  B. As found in this intercomparison:
    1. By U. G. I., direct measurement.......... 3B = 0.529
    2. By computation from U. G. I. measurements on lamps with the Lummer-Brodhun photometer and a Crova solution calibrated by a method involving the flicker photometer .... 3B = 0.536

From the above comparison, it is apparent that the group of eight, as well as the group of six, is as nearly normal as it is possible for a small group to reproduce average-eye values with the photometers mentioned.

Although in the earlier measurements made by the Bureau of Standards no method of selection of observers was employed and the illumination used was that employed in other work done at the Bureau and was much lower than that used in the recent investigation of Crittenden and Richtmyer, nevertheless it appears from the agreement in the above values that the considerable deviations from the mean of some of the observers were such that the plus and minus deviations substantially counterbalanced each other, and the figures then obtained by the Bureau correspond closely to those now obtained by an average eye working under the higher illumination used by the investigators mentioned. Of course, it would not be expected that such deviations

would all be in one direction, but that they were averaged out so completely was a matter of good fortune.

X. CONCLUSION.

The results of this intercomparison show quite conclusively that in each laboratory, regardless of the kind of photometer used, even though a considerable color difference was involved, each observer maintained a fairly constant criterion with respect to the mean. The same is true of each laboratory in respect to its relation to the mean of all, as judged by the measurements on the glasses and those on the lamps made some months afterward.

Considering the difficulties involved in the measurements, the different characteristics of observers and the wide difference in illumination employed, covering probably a range of ten times, the agreement among the laboratories must be considered remarkably good.

It is evident, however, that measurements to establish standards involving a color difference should be left as much as possible to the standardizing laboratory where the observers must be carefully selected and a considerable number employed and the kinds of instruments and the conditions of illumination, etc., definitely fixed.

An examination of the Bureau's observers who took part in this work shows that their mean characteristic is very approximately the same as that of the "average eye" as determined from the test of 114 observers taken at random from the Bureau's scientific employees.

Further evidence is obtained as to the accuracy of the values assigned to a group of 1.5-wpc. tungsten standards used in a previous intercomparison with National Physical Laboratory of England.

The authors express the Bureau's appreciation of the co-operation of the laboratories, and of those who represented them, in carrying out this investigation.

DISCUSSION.

Dr. C. H. Sharp: These tests are of great interest. They are of a kind which we all like to see the Bureau of Standards undertake, extending the limits of accuracy of standards beyond the point where it is practicable for laboratories of a commercial character, and bringing into the results not only their own observations, but the information, the experience and the observations of other laboratories where good photometric work is carried on. When all is said and done, the differences that have been found are small, and I think that that shows that all the laboratories have been substantially on the right track. It is gratifying to know that as a final result it will not be necessary for the Bureau of Standards to change the ratio between the tungsten standard and the four-watt carbon standard. I have not been able to see from the paper quite the reason why results are grouped so entirely by laboratories. Where similar methods are used, is it not a question of observers rather than a question of laboratories? If it is a question of observers, there would seem to be relatively little reason for grouping the laboratories excepting from the fact that the observers at the Bureau of Standards have been subjected to a special investigation for their color perception, which should give them a greater weight than would otherwise be the case. I understand the conclusion is that while the results are all very close to the average, yet because of this investigation of observers and because of the concordance obtained by the different methods in the work of the Bureau of Standards, the results obtained at the outside laboratories may be quite set aside, and the results of the Bureau of Standard tests alone taken as establishing, or as confirming the values which they already had. I should like to know whether there is any possibility that the fact that similar methods of testing observers were used at the United Gas Improvement Company laboratories and the Bureau of Standards had anything to do with the fact that the results of the final comparison of the U. G. I. observers and the Bureau of Standards observers came out very much the same; whether if some other criterion for color sensitiveness of the eyes of observers had been used, results might not have been different. I wish in closing to have the pleasure of thanking the

authorities of the Bureau of Standards for giving us an opportunity to cooperate with them in this work.

Dr. G. W. Middlekauff (In reply): Replying to Dr. Sharp, I would say that the results were grouped by laboratories for several reasons: 1. because we believed it would be of interest to the laboratories themselves, as well as to us, to know how their values compared, one with another; 2. because the purpose of the investigation was to determine the agreement which might be expected among different groups of experienced observers working in different laboratories, by the same method and also by different methods; 3. because in the recent investigation by Crittenden and Richtmyer, which was begun and completed while this intercomparison was in progress, it was found that the Bureau's group of observers represents very closely the average or normal eye, and hence, so far as obtaining a value for use as a basis in the establishment of standards is concerned, nothing was to be gained by taking a mean value in the absence of any knowledge of the relation of the other observers to normal.

In reference to Dr. Sharp's second question, it may be said that the results of the final comparison of the U. G. I. observers and the Bureau's observers, as shown by the values on glass 3B, came out very much the same independently of any method of testing observers. In each laboratory the results referred to were based upon a large number of observers, which in each case was assumed to represent the average eye. The Bureau had 114 observers who were taken at random by Crittenden and Richtmyer, the only qualification being that they have had some years of experience in scientific observations, and it was found that the results by this group were the same with a Lummer-Brodhun photometer as with a special flicker, both photometers being used under certain specified conditions. Although the number of observers used as an average-eye basis in the U. G. I. laboratory was smaller, it appears to have been sufficiently large to obtain a value equal to that obtained at the Bureau. It seems reasonable to conclude that all photometric tests of observers which are based on the average eye must give the same results.

We have not made sufficient progress in our investigation of gas-filled lamps to warrant a definite reply to the question raised

as to whether the voltage-current-candlepower characteristics are the same as those of vacuum tungsten lamps. However, in view of the changes in bulb form and capacity, differences in gas pressure, kinds of gas used, variations in heat conduction, etc., it appears quite improbable that a single equation of the form used for vacuum lamps and having the same constants will apply generally to gas-filled lamps.

CANDLEPOWER MEASUREMENTS OF SERIES GAS-FILLED INCANDESCENT LAMPS.*

BY RALPH C. ROBINSON.

Considerable discussion has taken place of late as to the best method of rating the candlepower of incandescent lamps. That the horizontal candlepower is far from satisfactory is very well shown by the lamps described in this paper.

Several mazda C lamps were made up for 6.6-ampere series circuits. They were of the so-called 80-candlepower type in the regular S-24½ bulbs. The filaments were spiralled in the form customary in this lamp, but were mounted in four different positions. Fig. 1 shows these mountings. The object of the experi-

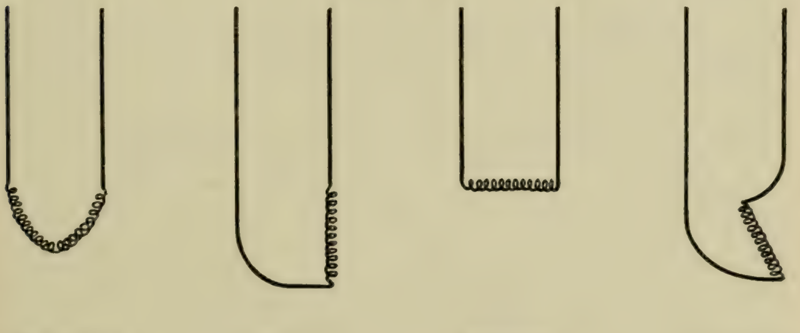

Fig. 1.—Different styles of filament mountings.

ment was to determine the reduction factor for the calculation of spherical candlepower from the mean horizontal candlepower. To make the lamps more nearly comparable, the filaments were all operated at the same temperature, 2,825° K. The method used in obtaining this temperature was that of color match described by Langmuir and Orange.[1] All candlepower readings were taken

* A paper read at the Mid-winter convention of the Illuminating Engineering Society, New York, February 10-11, 1916.

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[1] *Trans. A. I. E. E.*, vol. 32, p. 1935, (1913).

while the current was held constant at that value which gave a filament temperature of 2,825° K. To make the candlepower reading easier and more accurate, blue screens were inserted in every instance between the standard lamp and the photometer.

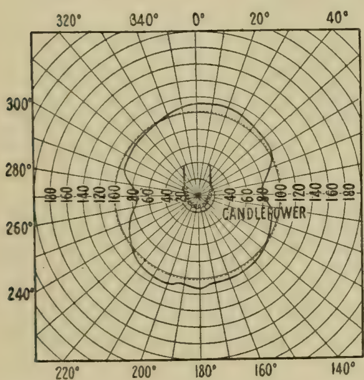

Fig. 2.—Typical curve showing distribution of horizontal candlepower, when filament is mounted V-shaped.

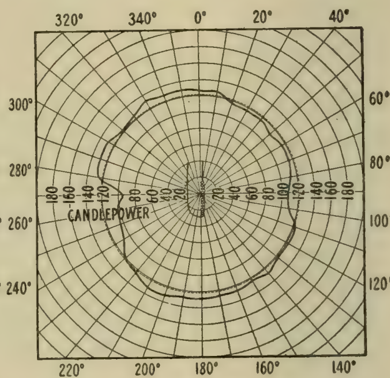

Fig. 3.—Typical curve showing distribution of horizontal candlepower, when filament is mounted vertically.

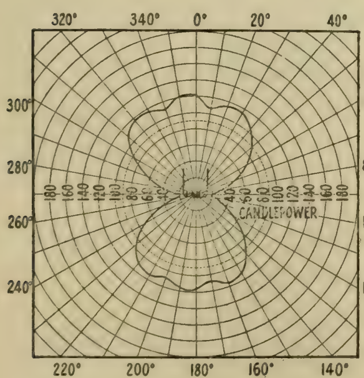

Fig. 4.—Typical curve showing distribution of horizontal candlepower, when filament is mounted horizontally.

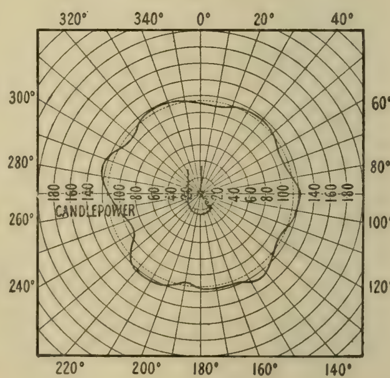

Fig. 5.—Typical curve showing distribution of horizontal candlepower, when filament is mounted diagonally.

As is well known[2], the mean horizontal candlepower of gas-filled lamps (mazda C) cannot be determined by the usual method

[2] Middlekauff and Skogland, *Elec. World*, vol. 64, p. 1248, Dec. 26, 1914.
Sharp, C. H., *Elec. World*, vol. 64, p. 992, Nov. 21, 1914; TRANS. I. E. S., vol. IX, p. 1021 (1914).

of rotating the lamp. For this reason, the candlepower was measured at every 10° around the lamp in a horizontal plane and the mean of these values taken. Typical curves of the horizontal candlepower for the different styles of mount are shown in Figs. 2, 3, 4 and 5.

The large indentations in the curves, noticeable especially in Figs. 2 and 4, are due to the fact that part of the light source was obstructed either by other portions of the filament or by lead wires. The smaller fluctuations (see Fig. 5) are due to slight twists in the filament, or to opening up of the spiral, producing more black body effect in certain directions than in others. The spherical measurements were made in a 50-inch (127 cm.) Ulbricht sphere, using the same method to get a good color match as was used in the horizontal determinations.

The results tabulated below are the average of several lamps of each type.

				Mean horizontal		Spherical		
Filament mounting	Volts	Amp.	Watts	Candle-power	Watts per candle	Candle-power	Watts per candle	Reduction factor
V-shaped	9.5	6.97	66.2	100.7	0.66	82.5	0.805	0.82
Vertical......	10.76	7.02	75.5	126.8	0.595	93.7	0.805	0.74
Horizontal ..	10.73	7.07	75.9	93.5	0.82	95.2	0.800	1.01
Diagonal.....	11.2	6.93	77.5	122.0	0.635	95.2	0.815	0.78

This table shows several very interesting results. The mean horizontal watts per candlepower are very different for the different filament mountings. This is due to the fact that the horizontal filament in certain positions is almost completely hidden by the lead wires, or by other portions of the filament, thus making the mean horizontal candlepower low. In the case of the vertical filament, very little is hidden at any point, so that the mean horizontal candlepower is high. The V-shaped and diagonal filaments are affected less than the horizontal, and hence their horizontal efficiency is better, although not so good as that of the vertical filament.

The watts per spherical candle are practically the same for the different types of filament.

In conclusion I wish to express by appreciation of the assistance of Mr. Edward Guyon, who made the measurements recorded in this paper.

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DISCUSSION.

MR. G. M. J. MACKAY: It seems to me that photometry by color match can hardly be too much emphasized as a very valuable adjunct to standard methods of photometry, particularly in interpreting the behavior of the lamp from the laboratory standpoint. Not only the life but the electrical characteristics of the filament are more simply and logically related to the temperature, than to any other factor. In dealing with the different types of lamps such as those Mr. Robinson has shown, and in comparing vacuum and the various gas-filled types, it is very useful to be able to refer other characteristics to the one common factor of temperature. The ordinary Lummer-Brodhun photometer, in conjunction with a calibrated blue glass filter, may thus be used as a very convenient form of optical pyrometer. With comparatively little practise, an operator can very soon learn to set up a lamp to within five degrees in temperature or 1 per cent. of the voltage.

MR. E. C. CRITTENDEN: From the data given in Mr. Robinson's paper it might appear that only one lamp of each type was measured. I should like to ask whether measurements were made on several lamps having the same filament mounting, and if so how the differences between individual lamps of the same type compare with the differences between the several types.

MR. G. H. STICKNEY: It must be recognized that series lamps, through their use in street lighting, encounter very different conditions from most multiple lamps and that this has a decided bearing on changes in rating. The majority of such lamps are used by central station companies in filling their street lighting contracts with municipalities. In many instances the candlepower rating of the lamp is written into the contract. Such contracts run for periods of years and do not expire simultaneously. As it is undesirable to make any change of rating that would interfere with the fulfilment of such contracts, or render them doubtful, it is obvious that it is important to avoid any unnecessary changes in rating and to consider very carefully any changes that are made.

There appears to be no serious objection to retaining, for the present, the mean horizontal candlepower rating for mazda C

lamps, while actually constructing and measuring the lamps in terms of mean spherical candlepower. However, the reduction factor should be such that the rated candlepower would represent as great a flux of light as formerly. It would seem to be a good plan to publish the lumens and mean spherical candlepower given by the various lamps and encourage the use of these terms so that later it may be practicable to withdraw from the use of the mean horizontal candlepower.

MR. R. C. ROBINSON (In reply): In answer to the questions asked, the values given are the averages obtained on several lamps. They are not measurements of four individual lamps. The variations between individual lamps of the same style were not very great.

The cases cited were the only style of filaments tried. They represent the largest possible variation in filament mounting. Lamps made with approximately the same filament mounting vary much less among themselves.

This paper was suggested by a series of experiments on mazda C lamps carried out in the laboratory. In order to accurately compare gas-filled lamps, it is necessary to have the filaments operating at the same temperature. As is shown in the paper, the spherical candlepower is much more consistent, and a much better indication of temperature than is the horizontal candlepower.

GASEOUS CONDUCTOR LAMPS FOR COLOR MATCHING.*

BY D. MCFARLAN MOORE.

Synopsis: This paper calls attention to the possibilities of the development of gaseous conductor lighting, describes the application of a new principle to the Moore vacuum tube lamps, and furnishes detailed information on one variety of the tube lamps which gives all objects the same color values as the best quality of daylight. The following subjects are also discussed: the underlying principles; the mechanical construction; the electrical factors; photometer tests, both intensity and spherical; methods of using; spectrophotometer tests; field of application; effects of line voltage variation; and the adoption of this lamp as standard of color values.

I. INTRODUCTION.

The method of producing useful light by electrically heating solids (the incandescent lamp) has made advances so phenomenal in the past few years that they were not even confidently predicted.

The first electric lamps had gas conductors (the agitated thermometers of the Monks and the globe of Hawksbee), and the light from the arc lamp of Sir Humphrey Davy emanated from both solid electrodes and the heated gas (air) in the arc. The vacuum tube of Geissler represented an interesting experiment and the incandescent lamp of Edison became one of mankind's greatest blessings; but when the gaseous conductor threaded its way through glass tubes several hundred feet long, its solid rival was far outdistanced, until it was rejuvenated by the commercial introduction of tungsten. But the race is still on, and it is believed that the solid conductor has developed most of its strength, while the gaseous conductor seems to be still capable of vast development.

Not only nitrogen but all of the rare gases, argon, neon, helium, xenon, and krypton, are interesting as gaseous conductors. Perhaps neon is the most interesting because of its predominant yellowish-red spectrum which lends itself almost ideally for effi-

* A paper read at a meeting of the New York Section of the Illuminating Engineering Society, November 11, 1915.

cient light production, and there are good prospects of its being feasible to obtain it in commercial quantities as a by-product of liquid air and oxygen plants. The theory has been proposed that considerable advantage results from its being monatomic because its atoms are immediately available to become luminescent without dissociating them from molecules. Neon has a maximum inertness and a minimum resistance. New gases will probably also be discovered that will aid in the solution of the problem of producing efficiently the short waves required.

The "filamentless" or "all gas" bulb lamp is confidently predicted. Some progress is being made with some of the detailed divisions or specific problems of this very large and complex subject.

When the material of the filament of the incandescent lamp was changed from carbon to tantalum and then to tungsten, the color of the light simply became a little whiter after each step had been taken, due principally to the gradual rise in the operating temperature of the filaments. But when the conducting gas of a vacuum tube is correspondingly changed, the color as well as many other of the salient factors are radically changed. Electrodes, for example, that are suitable for one gaseous conductor are entirely unsuited for another gaseous conductor. Moreover, gaseous conductors are far more easily destroyed than solid conductors. Ultimately, means will be discovered for obtaining lamps having lives of commercial length from probably all the feasible gases; but, at present when many such gases are used, the only commercial way of maintaining their life is to replenish them with gas while in operation and practically continuously. This was the purpose of the automagnetic gas feed valve which was applied by the author to one form of the Moore lamps, in various types, as described in a paper presented to the American Institute of Electrical Engineers, April 26, 1907, and another to the Illuminating Engineering Society, March 17, 1910.

It is a fortunate scientific fact that the passage of an electric current through pure carbon dioxide produces a light that causes all objects illuminated solely by it to have exactly the same appearance as they do when exposed to skylight of the best quality. Glass tubes filled with carbon dioxide and equipped

with automatic feed valves have been used for a number of years in almost all countries as the standard for color values in the textile industry. But the magnetic gas feed valve, although a comparatively rugged scientific instrument, yet of great sensitiveness, like the telephone, was, nevertheless, particularly difficult to commercialize with portable forms of the vacuum tube lamp. Therefore, it was highly desirable to accomplish the same purpose in a far simpler manner.

II. A NEW LAMP—GENERAL DESCRIPTION.

Fig. 1 shows one form of the Moore color matching lamp which is provided with a new method of automatically feeding CO_2 to the gas column, from which radiates the light of the desired quality and quantity. Besides solving the problem of the subdivision of the long tube system, this lamp possesses many advantages over previous types of color matching lamps. Instead of resting upon a table, this new unit is designed to be suspended similarly to an ordinary arc lamp.

This unit consists of two distinct parts, the upper or transformer position, and the tube lamp proper which is contained in the long sheet metal case, provided with a mogul incandescent lamp screw base, so that it can be screwed into or removed at will from the lamp receptacle attached to the bottom of the transformer. In other words, the tube lamp portion of this new outfit can be used in a manner similar to that of an ordinary incandescent lamp, in that this tube lamp can be removed and a new one screwed into its place. The new tube lamp has no external magnetic feed valve or gas supply tank, etc., but is entirely self-contained.

III. PRINCIPLES OF A NEW METHOD OF FEEDING.

Figs. 2 and 4 show the interior construction of the apparatus. The new and important principles upon which this unit depends for its operation are such that simple light giving vacuum tubes can now be constructed, if desired, of almost any length or candlepower and with various gaseous conductors.

Inside of the light-giving vacuum tube and directly behind the end of each electrode, there is a small glass bulb about 1 in. (2.54 cm.) long and ¾ in. (1.90 cm.) in diameter which contains a powder serving as the source of the desired gas supply.

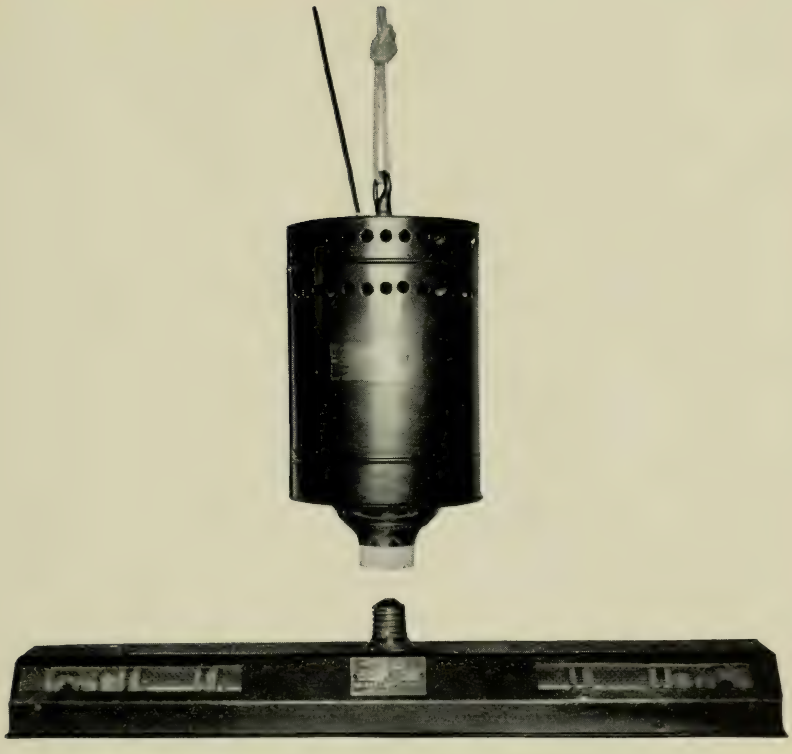


Fig. 1.—Lamp separated from transformer.

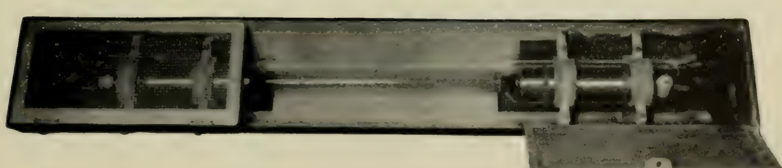
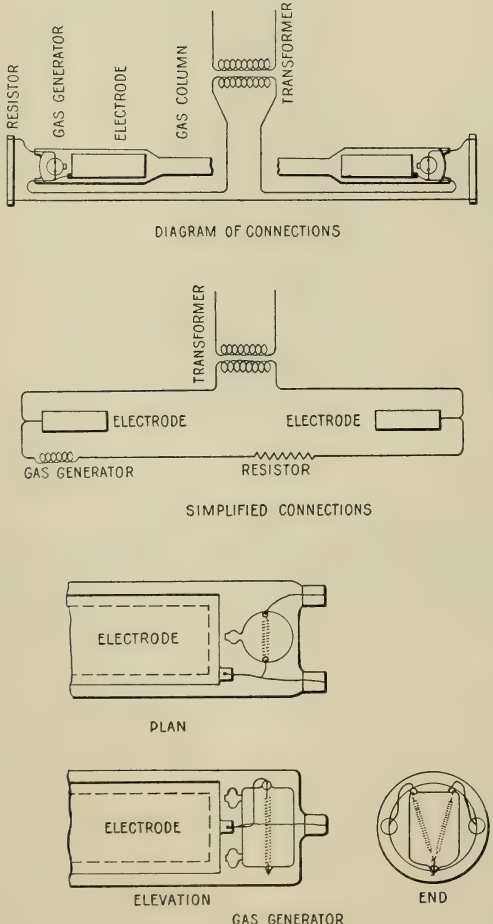


Fig. 2.—Bottom view of lamp.



Figs. 4, 5, and 6.—Diagram of lamp.

When attenuated carbon dioxide gas becomes a conductor of electricity, it is almost immediately destroyed, being chemically changed from a gas to a solid which is deposited on the interior of the electrodes. Hence, unless the glass tube is continually supplied with carbon dioxide, the lamp will cease to operate, which action, however, is prevented by the influx of gas in exactly the right quantity automatically generated from the calcium carbonate by means of heated resistance wires imbedded in it.

To make this thermal method of gas generation practical, it was necessary to utilize a transformer of constant-current characteristics, thereby providing a system that functions in a manner comparable with that of the old automagnetic feed valve system, yet vitally differing from it as regards the position of the pressure cycle on the ampere-pressure curve.

From Fig. 3 it is seen that with the automagnetic feed valve the cycle indicating the degree of vacuum in the tube is located to the left of the point of the maximum conductivity, *X*, while with the auto-thermic feed it is to the right. That is, with the automagnetic feed, the current passing through the tube gas column increases in value when gas is needed, but with the autothermic feed it decreases below the line *YZ*. In both instances the current automatically and continuously oscillates slightly above and below the line *YZ*.

It is also apparent from this curve that the normal degree of vacuum (gas pressure) is less for the new auto-thermic tube than for the old automagnetic tube, and therefore the efficiency of light production is correspondingly better. However, the ampere range covered by this cycle of rise and fall is so small with the autothermic tube that it is not detectable by either a delicate ampere meter or the eye, the light intensity being subject to very minute variations.

The action of the gas generator should be studied in combination with the circuit connections and the transformer. From Fig. 4 it is seen that the potential from the transformer is impressed on the two electrodes, but in shunt to the two electrodes are the two small glass tube gas generators at the ends of the electrodes, and that a resistor is located near each of the gas

generators. Of course, aside from constructional reasons, only one gas generator and one resistor is needed, as shown diagrammatically in Fig. 5.

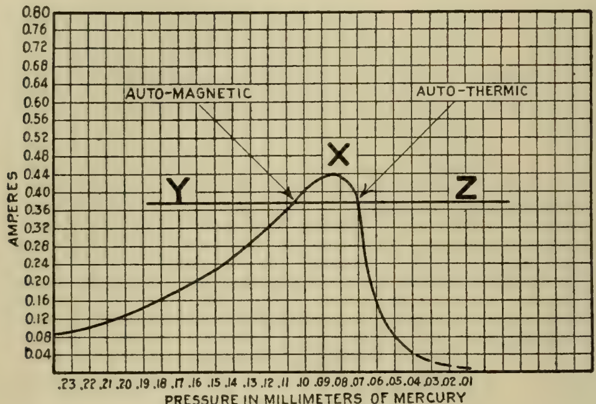


Fig. 3.—Ampere-pressure curve.

Due to the passage of the electric discharge through the gas column, the gas is consumed and the degree of vacuum therefore becomes higher, the resistance of the gas column increases, and a correspondingly greater current is therefore shunted through the gas generators which furnish momentarily an increased volume of gas due to the greater temperature, until the maximum current permitted by the constant-current transformer has again been reached and then most of the current passes through the gas column and the remainder through the shunt circuit of the gas generators. Although this varying action appears almost imperceptable in practise after the lamp is thoroughly started, the current changes during starting can be noted.

IV. ELECTRICAL AND THERMAL PERFORMANCE.

After such a lamp has been in operation for several hours and then allowed to cool off, over night for example, it will be found on starting that almost no light appears for about a half minute, generally due to gas absorption, but that the current through the gas generators is at its maximum of about 0.08 ampere; as gas is generated the current rapidly falls to about 0.025 ampere at

which value it remains practically constant after the gas column current has increased to its normal value. That is, the automatic action of the apparatus is so remarkably sensitive that it holds the degree of vacuum in the tube within the very narrow range of probably about 0.001 of a millimeter. While the gas is being generated during the first few minutes after current is sent through the circuit, the gas column is unsteady and the lamp current reaches a maximum and then suddenly decreases by about 20 per cent. and the light becomes steady. The tube case reaches its maximum temperature in about half an hour and then its current has about the same value as that of the starting maximum. Test data relating to the starting characteristics appear in Table I.

TABLE I.—STARTING CHARACTERISTICS OF LAMP.

Time	Pressure in mm.	Volts	Amperes			Watts
			Primary	Gas column	Gas generator	
3:20	0.03	120	1.7	0.02	0.08	125
3:21	0.06	120	2.1	0.15	0.07	134
3:22	0.07	120	3.8	0.28	0.06	186
3:23	0.075	120	5.5	0.36	0.04	250
3:24	0.072	120	4.7	0.32	0.03	230
3:50	0.076	120	5.6	0.37	0.025	255

The last line of this table shows the major electrical factors involved when the lamp has been fully started and is in normal operation.

Design details of the gas generator are shown in Fig. 6. The life of the tube lamp, without the tube blackening or the light becoming unsteady, is approximately 300 hours. An examination of the aluminum electrodes after a 300-hour service test shows them to be coated on the inside by only a thin dark deposit that is comparatively hard.

Various carbonates of differing dissociation temperatures have been tried and considered, but dry calcium carbonate of proper fineness has proved satisfactory.

The lamp is provided at each end of the tube case with an enamel resistor of about 8,000 ohms resistance. The glass tubing surrounding the electrodes is 1¾ in. (4.44 cm.) in diameter, but it was found advantageous to have the 12 in. (30.48 cm.) gas column confined to a glass tube reduced in diameter to ⅞ in.

(2.22 cm.) thereby improving the light intensity, its steadiness and freedom from striations. Striations may also be caused by mixed gases, and, of course, the usual procedures as regards heating, etc., during exhaustion are followed to remove all traces of moisture thereby also insuring the color value or pure CO_2.

The sheet metal case for holding the tube lamp acts as a reflector and suitable shade for the light-giving tube. The character of the reflecting surface has always been a factor of prime importance in connection with a lamp of perfect color values. After considerable experimentation, a number of years ago, a paint suitable for covering reflecting metallic surfaces was decided upon, and it still proves itself to be superior to all others as regards the permanence of its pure dead white surface which never turns yellow, as paints containing oil always do. It will withstand comparatively high temperatures without blackening or peeling off. It has recently been applied with marked success to the inner surfaces of large spherical photometers. This paint is simply a mixture of pure cellulose lacquer (amyl. acetate and celluloid) and pure zinc oxide in the proportions of 3 to 1. It is preferably mixed in small quantities and immediately applied with a soft brush to the metal surface, which must be free from grease. Two hours later a second coat can be applied in short brush strokes.

V. INTENSITY AND MEAN SPHERICAL CANDLEPOWER.

The intensity of the illumination at various distances below the tube lamp was determined by the use of a carefully calibrated Sharp-Millar photometer as follows:

TABLE II.—ILLUMINATION INTENSITIES AT VARIOUS DISTANCES FROM LAMP.

Vertical distance from center of tube. Inches	Foot-candles
2	212
4	114
6	65.2
8	42.7
12	23.8
24	6.98

The values from Table II are plotted in the curve shown in Fig. 7.

Most dyers using the lamp soon become accustomed to holding their samples quite accurately at a distance of about 5 in. (12.7 cm.) from the edge of the tube lamp case—thereby always obtaining a uniform intensity of about 100 foot-candles from the clear glass tube. This illumination is more than ample to produce a perfectly uniform product and eliminate loss involved in redyeing, etc. Since the energy consumption of the lamp is very low, it is recommended to be to the best interests of the user to cease entirely from attempting to depend upon the varying qualities and quantities of natural light and to utilize solely the Moore lamp.

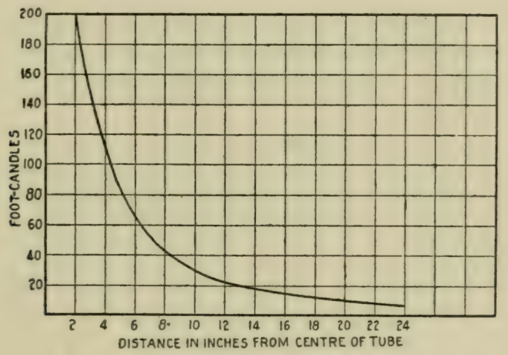


Fig. 7.—Distance-foot-candles curve.

The total light flux of this lamp was determined by placing it within a large (40 in.) spherical photometer. The Weber photometer was carefully calibrated. The color difference between the decidedly bluish spot and the surrounding reddish ring was very marked, but the readings of two observers checked each other very closely. The tube casing was black and may have introduced some error because its total surface was great as compared with the interior area of the sphere. Probably the results can be assumed correct within 10 per cent. The measurements indicated an average of 6.7 mean spherical candlepower (84.1 lumens) with 37 amperes passing through the tube and a total consumption of 250 watts.

Although the specific consumption in watts per lumen is high, it should be borne in mind that this factor is of minor importance in the solution of the problem of producing a light all of the color

values of which from the faintest shades of violet to the deep reds are perfect. The light efficiency of the gas column itself is comparatively high, the loss being in the electrodes. It will be remembered that even when the electrode loss amounted to about 30 per cent. of the total watts used in CO_2 tubes of great length, the specific consumption in watts per candlepower was below 3.

The color-matching, gaseous tube lamp as a luminous source is particularly adapted for the purpose intended; it is possible to use the light a very short distance from the tube source, yet the form of the lamp is such that a diffuse illumination is well distributed over a relatively large area.

The shade-reflector entirely shields the tube from direct vision, although it is to be noted that the brightness of the naked lamp in apparent candles per square inch amounts only to 0.22.

VI. SPECTROPHOTOMETRIC DATA.

Colored objects have the same appearance if they are viewed solely by light of the same spectral composition; that is, having the same relative intensities of each of the colors. A particular variety of natural light has been accepted for ages as the standard light under which the values of all color may be determined in a standard manner. But this particular variety of natural light in most countries is probably not available one half of the days of the year, therefore, it is apparent that an absolutely constant artificial duplication of the desired form of natural light is not only valuable and extremely useful but far preferable for exclusive use, if all the most delicate shades of all of the spectral colors are entirely accurate reproductions of those of the best quality of natural light.

Since thousands of shades of colors reflected from scores of differing materials have been pronounced as entirely satisfactory by probably many hundreds of the world's best color experts, it may seem superfluous to cite only a few specific examples brought to the author's personal notice; but it nevertheless may be well to record that all of the several hundreds of colors listed as follows have been found to have exactly the same appearance whether viewed by proper north light or by the light of the above-described color-matching lamp.

The "Standard Color Card" of the Textile Color Card Association.

"Color Maching on Textiles," David Patterson.

"Substantive Dye Stuffs on Cotton Piece Goods," Badische & Co.

"Woolen and Worsted Sample Books."

Duplan Silk Co., Sample Books.

Goode Bedin Silk Sample Books.

Also Aktiengesellschaft fuer Anilin und Soda Fabrikation Yarns.

American Thread Co.—Samples

Peerless Plush Manufacturing Co.—Samples.

Tide Water Oil Co.—Petroleum Purification.

Weidmann Silk Dyeing Co.—Samples.

One is very much surprised when he sees for the first time a sudden demonstration of the great differences in colors from their daytime values when viewed under the light from almost any of the common lamps. The light from all of these lamps is very deficient in blue light and entirely too abundant in red light. Therefore, for example, all heliotropes, lavenders, purples, etc., have a decidedly reddish tinge instead of their correct bluish predominances. Moreover, blues look black and many greens, brown. This result is attributable to the dependence of the lamps on the incandescence of solids none of which will permit of a temperature sufficiently high to produce a suitable spectrum. The lower the operating temperatures of the incandescent filaments the greater the divergence of the light from correct color values.

Of course, all forms of lamps giving light with continuous spectra have *some* wave-lengths corresponding to all the colors of the solar spectrum, but the great difficulty lies in the extremely small number of the short waves.

The specific problem of producing an entirely correct light for color matching must not be confounded with that of "obtaining a good quality of light for stores, etc." In connection with the color-matching problem there has been too much unnecessary confusion regarding the definition of the proper natural light for color judging. The assumption is commonly made that "average

daylight" and natural light are synonomous and the question is asked here and in Europe, "'What is daylight?" There are all kinds of daylight. In the author's paper in 1910, referred to previously, an attempt was made to differentiate between "daylight" and "sunlight." Daylight is extremely variable in both color and intensity. Scores of observations in a variety of climes of "skylight" and "daylight" and "sunlight" have even been averaged and the result proposed as a standard and also expressed in a black-body temperature curve. The lower the temperature of an assumed standard curve, the easier is the problem of obtaining its duplication by screening methods. Others have stated that "a true average daylight quality is that of sunlight at noon on a clear day," or have represented "sunlight" and "average daylight" by the same curve.

In endeavoring to select the correct light for color judging there is no justification for claiming that this is synonomous with attempting to determine upon exactly what "average daylight" or average natural light is; such a task is seen to be impossible when one considers the myriads of varieties of the light of the sun as it reaches the earth. "Average daylight" is not wanted by the dyers and other color experts, even though it could be definitely determined upon. Neither do they want a light that is too "white." No condition of natural light should be considered that is clearly unsuitable for the only purpose desired, namely, color judging. Nor does the correct color matching spectrum necessarily correspond to a black body or complete radiator at 5,000° or 6,000° C. or to a so-called "white light"—even if not produced in an improper manner by mixtures of two or three colors.

In several text books it is stated that the partial discontinuity of the CO_2 spectrum cannot be detected by the eye as regards any color values.

From remote ages to the present hour, the quality of daylight desired has been defined and used within comparatively narrow limits, namely, the light which enters into a window from a clear north sky at an angle of about 45° and preferable about mid afternoon, with a clear sun shining in the south. Light of this kind varies by not more than a few per cent. and it corresponds very accurately to the spectrum color values of carbon dioxide.

The light from the carbon dioxide tube contains less blue than that from a clear sky at the zenith and more than that from the sky near the horizon. This fact was determined in 1909 by the U. S. Bureau of Standards and corroborated later by others, including English and German physicists.

Since colored goods are often judged at different hours of the day it might be claimed that therefore the particular light to be decided upon should be an average and not the 45° light. But such a proposition is illogical and untenable, on the premises which stipulate that the specific problem is to determine the spectrum most suitable to be adopted as the standard, and which is to be used as the fixed position from which to measure values in either direction.

Any other course is unscientific and impracticable. For example, it is obvious that no dyer or artist would attempt to match colors or pass upon any certain shades desired by natural light either very early in the morning or late in the afternoon. Neither would he do so at noon or during a storm, and of course he would never attempt to use the direct rays of the sun.

These compelling considerations leave no ground for doubt that the manufacturers of the most uniform colored products of the past and present, as well the greatest artists, made no mistake in choosing 45° light from a clear north sky.

Unless there be a standard scale of color constants for reference, it is impossible to arrive at quantitative results or accurately reproduce colors. Unless such a standard artificial daylight be available the whole subject rests on a memory of sensation, but with the best quality of daylight made to order, in a practical manner, a definite match can be repeated at any time.

Even though certain goods (dress goods, for example) are to be worn solely at night under ordinary incandescent lamps, the only correct way to purchase them is to color measure them first in terms of the standard and of course this is also necessary in their manufacture.

A critical analysis of the spectral characteristics of the light from the above described lamp, as made in the illuminating engineering laboratory of the General Electric Company, is reproduced below.

SPECTROPHOTOMETRIC TEST OF THE MOORE LAMP FOR COLOR MATCHING.

The spectrum of the CO_2 gas when subjected to the discharge between electrodes is a typical gas spectrum; that is, it consists of numerous lines and bands of light scattered throughout the range of the visible spectrum.

In photometering this lamp certain precautions had to be taken to obtain accurate data. A brief description of the method of testing will aid in understanding the curves and other data given.

The tube was laid on its side so that it was in direct line with one slit of the spectrophotometer. This arrangement gave direct light without the use of any reflecting or diffusing media. Also, the tube, with its luminous gas is transparent so that light reflected from a small section of the reflector supporting the tube also entered the slit. The paint used on the inner surface of the reflector is known to be very slightly selective in its reflective powers and this arrangement gives a mixture of direct and reflected light similar to the actual light from the complete unit. The difference between the direct light and the composite light is probably beyond the limits of the test.

An inspection of the CO_2 tube when in operation will reveal a number of nodes in the luminous gas. These nodes are in constant motion when the tube is first started, but when the lamp is thoroughly heated, the nodes are apparently stationary. To guard against a movement of the node under observation introducing an error in the readings, the entire length of the spectrum was gone over four times in succession. There is a systematic difference between the four sets of readings that indicates a slow rise and fall in intensity. This variation amounts to about 3 per cent. either way from the average.

There is probably a slight "breathing" action due to the supply of CO_2 gas exceeding and then falling short of the consumption. So far as can be observed from the test data, the changes that occur affect only the total intensity and are without effect on the color composition.

The width of the spectrum as observed in the telescope of the spectrophotometer was divided into twenty-two equal parts. The telescope slit was then set so that exactly one division was visible

at a time. Each of these divisions was balanced separately against a tungsten lamp at 2,560° K. and the corrected reading is indicated by a circle on the test curve, Fig. 8. Each circle on the broken curve indicates the average intensity over a range half way to the adjacent circles. By this arrangement every line in the spectrum is included in the test data and no line is included twice.

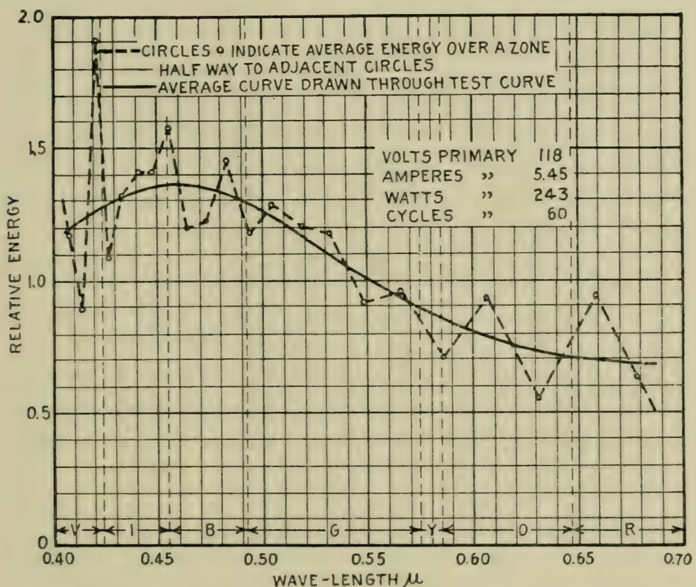


Fig. 8.—Spectrophotometric test Moore tube light for color matching.

The distance between circles, Fig. 8, is greater at the red end of the spectrum than at the violet end. This has some effect on the apparent evenness of the spectrum. The closer the points are taken, the greater will be the variations in intensity. If extremely small spacing were used some of the readings would fall near zero and others would be twice or more the height of the average curve. This necessarily follows for the banded character of the spectrum. If a different width of telescope slit is used or the location of the arbitrary parts of the spectrum is changed, the resulting intensity curve will be changed in its details, but the average curve will not be changed. The average curve, Fig. 8, was drawn by eye. This curve is the really important one of the

two because it gives a good idea of the effective color characteristics and it may be used to compare with the spectra of other lines and continuous spectra.

The probable effect of the irregularities in the test curve will be taken up later when color matching is considered.

Numerous investigators have determined the quality of the natural light of day. Several years ago, Dr. H. E. Ives collected much of the available data and adding some of his own determinations presented average curves before the Illuminating Engineering Society.[1] It is, of course, understood that these data are not in any sense final. They merely represent the most probable values from the available material. The quantity and quality of natural light varies tremendously with the time of day, the seasons of the year, the geographical location and the section of the sky from which it comes.

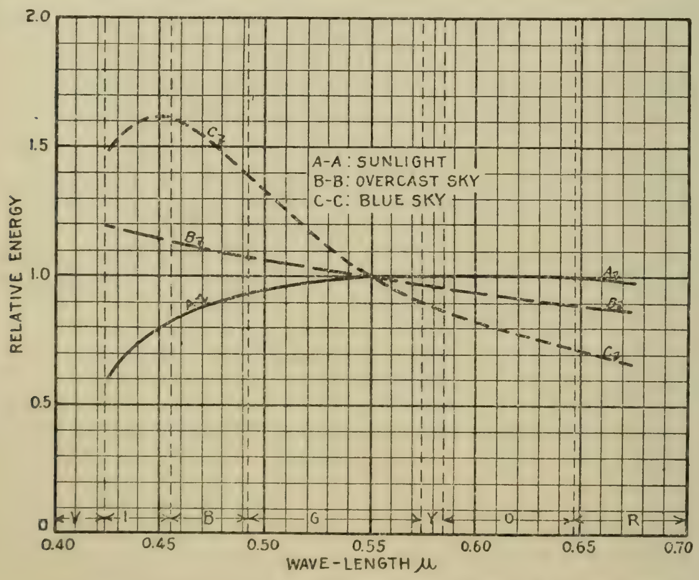


Fig. 9.—Spectrophotometric test special composition of natural light.

On Fig. 9, the curve marked A-A gives the energy composition of sunlight as it is received at the earth's surface. The intensity of energy in the red, orange, yellow and green is practically uniform but there is a sharp decline in the blue and violet.

[1] TRANSACTIONS I. E. S., vol. 5, pp. 189-208.

This makes the red end of the spectrum predominate and there is obtained the familiar yellow of sunlight.

The atmosphere acts in different degrees upon the different colors of the light from the sun. The red and yellow rays are transmitted directly with only a small loss. The shorter waves, the blues and violets, are to a considerable extent scattered by the dust particles in the air. These particles then become secondary light sources and there results the characteristic blue of the clear sky. The other colors are not totally lacking in this scattered light, however, but have relatively less intensity as indicated by the blue sky curve in Fig. 9. There is one feature of this curve that calls for particular notice. At wave-lengths 0.425μ there is a sharp decrease in the intensity. A similar decrease occurs in the sunlight spectrum, so that from these two curves one would be led to think that the spectrum of the primary source, the sun itself, decreased rapidly in this section.

If the sunlight spectrum be added to the blue sky spectrum, after giving to each a value proportional to their relative intensities, there is obtained an approximation of sunlight before it enters the earth's atmosphere. The operation is just the reverse of that carried out by the atmosphere; that is, the original composition of the light of the sun has been restored. The restoration is not complete, however, for part of the light is transformed into longer wave-lengths and thus lost as light, and this last portion cannot enter into the intensities shown by curves A-A and C-C.

The addition of direct sunlight and skylight indicates that the sun has a temperature of 5,000°. If, however, the losses in the atmosphere are taken account of, the indicated temperature is higher, or about 6,000°. The energy curve of a black body at 5,000° is higher at 0.450μ being 0.75 in comparison with 0.60 on the sunlight curve. At the other end of the spectrum the 5,000° curve is a few per cent. lower. This 5,000° distribution is often referred to as the distribution of average daylight.

There is another combination of natural light that has not been referred to. This is the light reflected from the clouds of an overcast sky. This light has an energy distribution similar to curve B-B, Fig. 9. This light appears to be much nearer white

than either direct sunlight or light from the blue sky. The energy curve shows that the proportion of colors is near a mean between sunlight and blue skylight. There might be a question raised about the straight section of curve between 0.425μ and 0.450μ, B-B, in Fig. 9. The original data indicate roughly a straight line, but when the other curves, A-A and C-C, are taken into account it would seem that B-B should decrease between 0.450μ and 0.425μ.

Thus four terms are used in connection with natural light; namely, sunlight, the direct rays of sunshine; blue sky, the light from a cloudless sky near the zenith; overcast sky, the light reflected and diffused by clouds; and average daylight, a combination of all three sources mentioned above, and often taken as being equal to the radiation from a black body at 5,000° absolute.

There seems to be considerable confusion in the use of the terms roughly defined above. Thus, there are several "white light" units on the market that give, not white light, but a bluish tinged light similar to that from a blue or overcast sky.

In taking up the gaseous-conductor color-matching lamp again, the question "What is really desired from a color-matching unit?" will be considered.

The apparent color of any surface is due to the combination of the incident light and that reflected from the surface. The "true" color then presupposes a "true" source of light, and this "true" light is then what must be duplicated by a color-matching unit. The choice of the best light for color work was made many years ago by people interested and working in colors. Direct sunlight, then as now, was avoided and the diffused light from the sky was much preferred. It was found that the brightness of the different parts of the sky varied during the day and that this variation was least in the northern section of the sky. This led to the general adoption by painters and textile workers of light received from a window facing the north. The composition of north light varies with the time of day, season, weather and many other factors, but in general, the energy composition lies in the space between curves *C-C* and *B-B* of Fig. 9. A clear blue sky gives approximately *C-C*, an overcast sky gives *B-B* and a

sky only partly filled with clouds gives some proportion between the two.

The modern color matcher uses a northern exposure or often an open space, but the direct sunlight is always excluded. The practise in regard to a selection of natural light is so universal that there is no doubt as to what model should be copied in a color-matching lamp. The determination of just what is the best section of the blue north sky, whether near the zenith or near the horizon, has not been definitely made, and neither is the exact proportion of cloud light determined, but the general limits are reasonably well known.

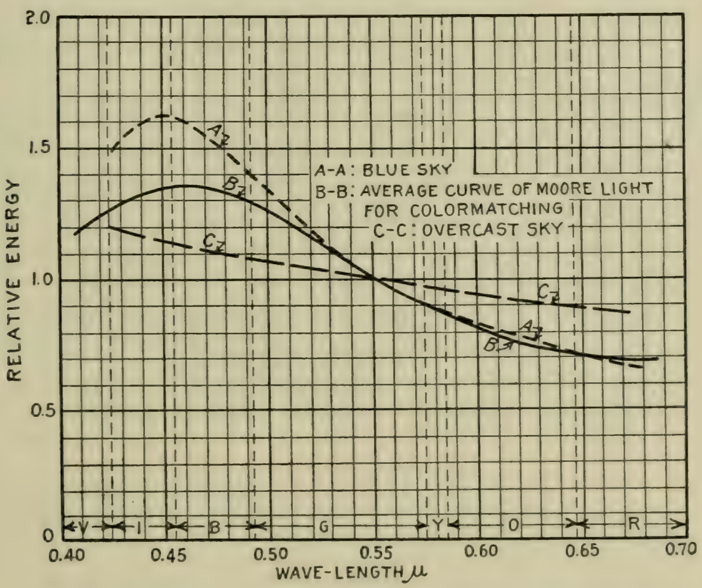


Fig. 10.—Spectrophotometric test Moore tube light for color matching.

The three curves of Fig. 10 are copied from the two previous C numbers in order to give a better means of judging how close the CO_2 tube comes to duplicating a north exposure. The location of the CO_2 curve between the two natural light curves in the blue end of the spectrum is about that which we would give it if we had control of the color composition. At the red end, the composition follows very closely the blue sky. The net result is a

good approximation of a blue north sky with a small amount of cloud light.

The test curve of the CO_2 lamp was seen to consist of a broken line that varied greatly between adjacent points. It might well be asked whether the irregularities that arise from the banded character of the spectrum might not have some effect upon the color-matching properties of the lamp.

The eye has very small analyzing powers. It acts more as an adding device—all the colors received from a colored surface are added by the eye to produce a single resultant color. It is true that one may think he detects the color composition of any composite color, but such a judgment carries small weight as will be shown directly. The lack of an acute analyzing action by the eye has an important effect on the results obtained with a banded spectrum.

Eight colors contained in the "Standard Color Card of America" were tested to determine what the actual color composition was. The results are given as coefficients of reflection in Figs. 11 to 18. The values indicated might be multiplied by the proper visibility factors to reduce them to quantities of light, but this would confuse rather than clarify the subject.

All samples of ribbon tested give a mixture of specular and diffuse reflection so that the apparent reflecting power is different as the angle of observation is changed. In making the test, readings were taken at about 20° from the angle of the specular reflection.

The colors are described in the card as being composed of a first, a second and a third color, the strength of coloring being also indicated. An inspection of the description of the composition of the different samples shows that in no case is the presence of more than two spectrum colors recognized. White, black and gray are included in the basic colors and where three colors are indicated, one of these non-colors is always included. This pretty clearly indicates the color limitations of the eye and has an important bearing on the lamp under discussion.

On the test curve, Fig. 8, there are two points at 0.415μ and 0.421μ that vary greatly in intensity although close together in the spectrum. At the other end of the spectrum there are two other points at 0.659μ and 0.677μ that differ in intensity. Assuming

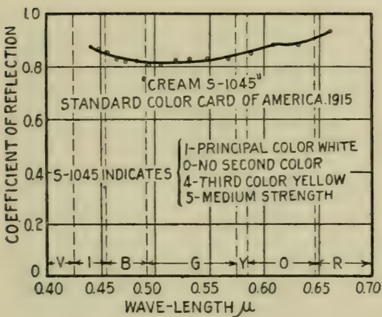


Fig. 11.—Spectrophotometric test coefficient of reflection.

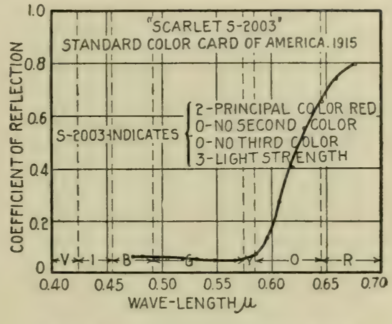


Fig. 12.—Spectrophotometric test coefficient of reflection.

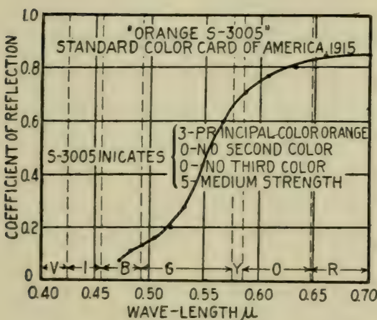


Fig. 13.—Spectrophotometric test coefficient of reflection.

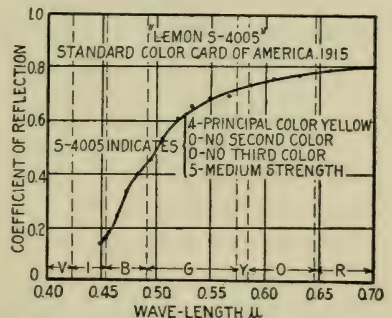


Fig. 14.—Spectrophotometric test coefficient of reflection.

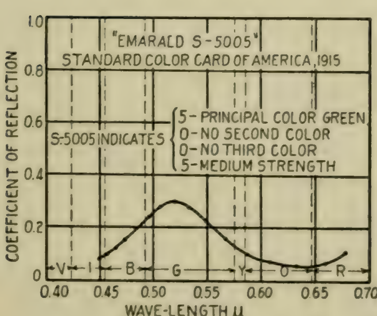


Fig. 15.—Spectrophotometric test coefficient of reflection.

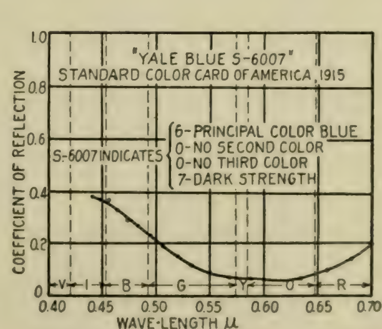


Fig. 16.—Spectrophotometric test coefficient of reflection.

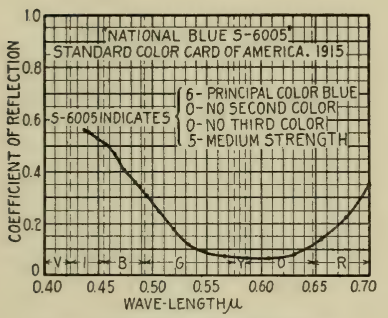


Fig. 17.—Spectrophotometric test coefficient of reflection.

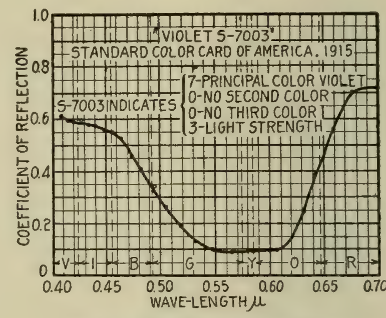


Fig. 18.—Spectrophotometric test coefficient of reflection.

a surface that reflected only in narrow bands at 0.415μ and 0.659μ, the other wave-lengths being totally lacking, the color of the surface would be purple, containing violet and red energy in the ratio $\frac{0.89}{0.94} = 0.95$. Another surface having two reflecting bands close to these, at 0.421μ and 0.677μ would have for the violet-red ratio $\frac{1.90}{0.64} = 3$. The first of these dyes would then have about equal proportions of red and violet and would appear purple. The second would possibly be purple also, but of a totally different kind because the violet is three times as strong in proportion as the red. Under the color composition indicated by the average curve, these two dyes would reflect the violet and red light in the proportion $\frac{122}{70} = 1.74$, and $\frac{126}{69} = 1.82$ These two ratios are not very different and aside from the slightly different spectrum colors used in each case, they would be very close in apparent color. With a reflecting surface as described above, there would be a great difference between the CO_2 tube and a unit having an energy distribution such as the smooth average curve. This great difference depends almost entirely upon the reflector having sharply defined zones of high reflecting power. If such zones do not exist then the high and low emission zones in the CO_2 spectrum will neutralize one another and give the effect of the average curve as drawn. It is

often stated as a generalization that all dyes and paints are impure; that is, they have not closely restricted reflecting zones such as was assumed in the numerical case above. In order to get some definite data on the subject it was decided to test some of the colors given in the "Standard Color Card of America," using some of the samples that seem to have the purest colors.

The cream sample, Fig. 11, has coefficients of reflection ranging from 0.81 to 0.93. These figures refer to only one angle. At other angles the reflection would doubtless be different because the colored samples show a strong tendency toward specular reflection. The test angle was about 20° from the angle of specular reflection, but on account of the small size of the ribbon, the angle could not be accurately controlled.

The coefficient of reflection for yellow light is not above the average for the spectrum. The coefficient in the orange and red is above the average and these colors give the sample its characteristic yellow or cream tint. It will be noticed that the test points fall along a fairly smooth curve and there is no indication of any sudden change in reflecting power.

The scarlet sample, Fig. 12, shows the sharpest change in coefficient of any of the samples tested. If the CO_2 lamp has a weak point in its spectrum distribution, it is in the red and where the spectrum lines are most unevenly grouped. It is necessary to reduce the energy values of the CO_2 spectrum to luminous values to make a comparison between it and blue sky light or any other source. The two sources give the following per cents. of red, orange and yellow light reflected from the scarlet sample, Fig. 12. The light from 0.576μ to 0.686μ is made equal to 100 per cent.

	Wave length in μ	Blue sky	CO_2
Red	0.686 to 0.645	13	16
Orange	0.645 to 0.596	70	70
Yellow	0.596 to 0.576	17	14

The apparent error of the CO_2 spectrum is 3 per cent. in the yellow and red. The data do not allow any closer calculations of the error. Referring to Fig. 11 the deviation from white, or uniform reflection, amounts to an excess of light in the red end of 11.6 and 0.9 per cent. excess in the blue end. Supposing the blue excess to neutralize 0.9 per cent. of the excess red, there re-

mains a deviation of 11 per cent. from white as seen under a perfectly uniform energy spectrum. An inspection of the cream sample, Fig. 11, will show that the 11 per cent. deviation from white has an exceedingly small effect in the apparent color and from this it may be inferred that the 3 per cent. difference in the yellow and red of the scarlet sample, Fig. 12, is beyond detection. This must not be taken as being proof that the irregularities in the red are without effect. It makes it appear probable that the color matching value of the CO_2 spectrum is all that can be desired, but the proof must be obtained by actual comparison of extremely pure red samples under natural light and the CO_2 tube.

The characteristic curve of the lemon sample, Fig. 14, shows that only the violet and indigo light are lacking and a very large deviation in any section of the light spectrum would be necessary to change the total color as added by the eye.

The reflection curve of the emerald sample, Fig. 15, is the only one of the seven samples tested that indicates plainly the apparent color of the fabric. From the curve, it is evidently green, but it would be difficult from the curve alone, to say what particular kind of green.

The coefficients of the two shades of blue, Yale Fig. 16, and National Fig. 17, show the presence of considerable red that is not apparent to the eye. From several minor similarities it is evident that the same dye was used for both, the concentration being different.

One of the most interesting and difficult of the samples tested was the violet, Fig. 18. The actual quantity of violet light from this sample is very small, possibly less than 1 per cent. of the total. The color sensation of violet is derived from the combination of the other colors from indigo to red. It is on colored surfaces such as these that the greatest difficulty in matching is found. The main component parts of the light are from opposite ends of the spectrum, and unless these opposite ends are well balanced in the light source, the effect is at once apparent. This is the reason that all purples are so markedly changeable under different lights. This, the ratio of violet to red in the CO_2 spectrum is 15 times as great as in the tungsten 2,850° spectrum. What appears blue with a trace of red under one will be a red with a trace of blue under the other.

A review of the reflection curves will show that the irregularities in the CO_2 spectrum will be absolutely without visible effect on most of the samples tested and only in the extreme case of crimson would any deviation from north sky light be expected, and this deviation, if it exists, must be detected by test rather than calculation.

It is obvious that the above splendid spectrophotometer data corroborate and justify the various claims made for the CO_2 spectrum in the other sections of this paper as well as in the paper on "A Standard for Color Values" presented by the author on March 17th, 1910.

VII. APPLICATIONS.

After seven or eight years of commercial use in all countries, it can be stated that the Moore carbon dioxide lamp is the only one that has always given absolutely satisfactory results as regards the color values of its light. It has been found indispensible to many manufacturers, notably in dyeing establishments for silks, cotton, wool, fur, feather, knit goods, hosiery thread and similar goods. In its new form its usefulness will also be greatly appreciated in the manufacture of such goods as millinery, neckties, gloves, carpets and rugs, wall paper, for lithographs and color process printing, paints, leathers, glasses, flowers, buttons, tiles, oils, etc. It will, furthermore, be found extremely useful in the merchandising of the various materials mentioned.

A good color matching outfit is practically an economic necessity; the highly paid dyer need not stop work in the early afternoons of the winter months losing not only his own time but interfering with the production of the mill. Often it will alone determine prompt deliveries because neither cloudy days nor dark hours of night need affect the operation of the plant. Its color-matching qualities are so accurate that textile mills and a score of other industries in which the matching of certain materials is a step in the operation can work at full efficiency at all times, avoiding mistakes and saving time and money. The accuracy of the light of the lamp is in fact such that under certain conditions it can be more thoroughly depended upon than the variable and uncertain daylight.

Ultimately the field for a lamp giving light that will really

project the most delicate shades of any hue throughout the night will be large. However, no form of color matching lamp will permanently satisfy the dyers, for example, unless the colors in the light are absolutely perfect at all parts of the spectrum.

This paper deals primarily with a single type of apparatus, but it is obvious that the principles involved in this lamp are applicable to tubes of any desired lengths and candlepower suitable for illuminating large floor areas and it is the belief of the author that the large majority of such areas used for commercial purposes will finally be flooded with artificial daylight if the cost is reasonably low. Consideration of the lighting of department stores, for example, in connection with the above premise, results in the conclusion that if artificial daylight were as easily attainable as incandescent electric light from solids, it would be desirable to have continuous daylight.

A light of standard colors is needed for the entire textile trade to enable it to decide upon or define accurately by number, the several score or shades most used, for example, "Navy Blue" and other familiar names, so that, at least some of the shades of colored goods can be duplicated by number. Over 2,000 different shades are in commercial use. Such standards can now be adopted not only throughout America, but also throughout the world.

At this date solid-conductor lamps seem efficient, but in the large majority of cases the lamps are so used that screens to reduce the excessive intensity are necessary, and thereby the purported efficiency is reduced by about 30 per cent. Gaseous conductor lamps will not be subject to this loss—they will need no screening; they have no glaring defects and neither will they need color modifiers. If it is desired to produce light with marked visual acuity or penetrating power, for example, a redish yellow light—it is necessary merely to choose nitrogen as the gaseous conductor.

VIII. EFFECT OF SERVICE VOLTAGE VARIATIONS.

The line voltage variations in many of the textile mills are far greater than they should be. They are generally due to the sudden throwing of large motors on or off the circuit. It is, therefore, necessary that a color matching lamp be able to withstand these

abnormal surges, not only as regards its ability to give a steady light or resist being ruined, but also that the color values of its light remain constant even though its brightness vary.

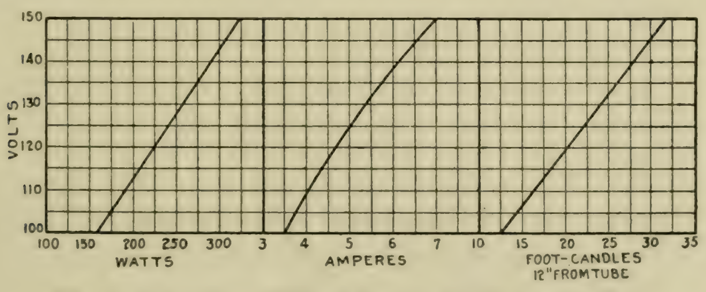
How well the above descriptive gaseous-conductor lamp fills these difficult specifications is shown in the following table:

TABLE III.

Volts	Amperes	Watts	Foot-candles 12 inches from center of tube
100	3.45	160	12.8
110	4.15	190	16.0
120	4.80	225	20.8
130	5.40	255	23.8
140	6.18	590	28.1
150	7.05	330	32.0

A voltage depression of about 16 per cent. simply reduced the light intensity; if still further lowered the light would have become unsteady. Likewise a voltage elevation of about 16 per cent. resulted in a corresponding increase of intensity and if further persisted in the high current would finally have overheated the tube in its case and too much gas would have been generated and the light would cease entirely, due to too low a degree of vacuum.

These results are shown in the following curves of Figs. 19, 20 and 21.



Figs. 19, 20, 21.—Characteristics of Moore tube light, showing effect of voltage variations.

ADOPTION AS THE STANDARD OF COLOR VALUES.

The following quotation formed the last paragraph of the paper presented by the author before this Society on March 17, 1910, upon which occasion a resolution was passed recommending the

suggestion for consideration by Council, but the author is not, at this date, aware of any further action.

"At various previous meetings of this Society the author suggested that some action be taken towards the adoption of a light of standard colors, and now realizing that at the present time no such standard has been adopted and believing that it is a matter of great and immediate importance and that there is a demand for such a standard by commerce and science, the author earnestly requests the president of the Illuminating Engineering Society to bring this matter to the early attention of the Council for consideration, and hopes that it may speedily result in an active committee being appointed to make thorough investigation and report its recommendation, with the ultimate idea of presenting the same before the International Conference on Electrical Units and Standards."

Since light is the source of all color, and since the carbon-dioxide vacuum-tube lamp during all these years has successfully withstood the scientific and commercial investigations of the color experts of the civilized countries of the world, the color qualities of its light are all that can be desired, it should be officially adopted.

The author wishes to acknowledge the valuable assistance of Mr. F. A. Benford who made the spectrophotometric curves given in this paper.

DISCUSSION.

Mr. F. A. Benford: The data of this test were not obtained in a manner that allows a close analysis of the distribution of spectrum lines. A calculation on the most unfavorable case among the colored samples tested showed that the difference in resultant color with a continuous sky spectrum and the banded CO_2 spectrum amounted to less than 3 per cent. in any one of the seven principal spectrum colors. I found that the reflection coefficients of the materials tested did not show any strong selective bands. None of the samples tested actually went to zero at any point in the spectrum and the slopes of the curves are very regular, so that I do not believe one could get a surface selective enough to match up with the high and low spots in the CO_2

spectrum and thus give a serious difference between this source and skylight.

I cannot give specific data on the distribution of spectrum lines. In making the spectrophotometer test, the spectrum was divided into twenty two parts and the energy measured in each without reference to the number or distribution of spectrum lines.

DR. W. C. MOORE: The flaming arc is more flexible as far as the quality of light goes than any of our other illuminants. By a proper choice of carbons one may obtain a light which is fairly close in its spectral characteristic to morning sunlight, or by the use of a different carbon, one which is close to noon sunlight plus blue skylight in its color.

As to the efficiency one may expect to see quite a development of the white flaming arc for color testing; that is, for determining the fastness of color. A very large number of experiments have been made in our laboratory in Cleveland along this line. One can readily see that an illuminant which will not only indicate the fastness of a color to light but which can also be used for color matching is a light source of great value. In using a flame arc for color fading the efficiency of the arc is very important.

LIGHT TRANSMISSION THROUGH TELESCOPES.*

BY F. KOLLMORGEN.

Synopsis: This paper deals with the loss of light and brilliancy in telescopes and similar optical instruments caused by reflection and absorption, and means of changing the reflecting power of glass surfaces by chemical treatment.

In submitting a paper of such a highly specialized nature to an assembly of illuminating engineers I am aware that I am asking you to give your attention to a subject rather foreign to your work. That I do so nevertheless is due first to the fact that all branches of modern science are so closely interrelated that it is impossible to say what feature of one branch may or may not be of interest to another, and, second, that I shall have to refer in this paper to some recent investigations of reflecting power of surfaces which I feel sure will be of interest to many of you.

As is generally known the amount of light energy which falls upon a glass surface is divided into two parts: a smaller one which is reflected back into the original medium and a larger one which continues into the glass and is refracted in it and, in the telescope, forms the image. The relative amounts of these two quantities can easily be computed by Fresnel's formula which for vertical incidence, and that is sufficient for the subject of this paper, reads

$$I = I_o \left[1 - \left(\frac{\mu - \mu'}{\mu + \mu'} \right)^2 \right].$$

In this formula I is the intensity of the transmitted light, I_0 the original intensity; μ and μ' are the refractive indices of the medium beyond and before the surface of incidence respectively. The part:

$$\left(\frac{\mu - \mu'}{\mu + \mu'} \right)^2 ,$$

therefore, represents the loss of light through reflection. It will be seen that this amount is the same when μ and μ' are ex-

* A paper read at a meeting of the New York Section of the Illuminating Engineering Society, January 13, 1916.

changed, that is, the loss by reflection is the same for light falling from air into glass as from glass into air. For very light crown glasses with an index of refraction of 1.5, this loss is therefore 4 per cent. at each surface. For a heavy flint glass (index over 1.62) it may be assumed to be about 6 per cent.; the transmitted light would therefore be 96 and 94 per cent. respectively. The same percentual loss occurs at the second surface of the lens; the total amount of light transmitted through a single crown lens in air thus comes to 92 per cent. in a flint lens 88 per cent., and in an achromatic doublet consisting of one crown and one flint lens, to 90 per cent. The loss through reflection at the cemented surface of such a doublet is so small that it may be neglected.

(I may interpolate here that optically a glass is called a flint glass if it has a relatively high dispersion, and crown glass if its dispersion is low. The higher dispersion is produced by an admixture of lead oxide. I have recently been told by a practical glass maker that in this country all glass that is absolutely colorless is called flint, whether it contains lead oxide or not.)

Even when a telescope is of comparatively simple construction the loss of light by reflection is quite appreciable. Take the case of an ordinary astronomical telescope, an optically very simple construction. Such an instrument consists of a crown lens and a flint lens composing together the objective, and an eye-piece comprising usually two separate elements, field and eye lens, which may be single lenses or achromatic doublets. The foregoing formula would give the total transmission as

$$0.92 \times 0.88 \times 0.92 \times 0.92 = 69 \text{ per cent.}$$

for the best possible case, and this amount would still be decreased by the absorption of light in its passage through the different thicknesses of glass. This absorption may roughly be assumed to be 3 per cent. per inch of thickness, though it varies with different glasses.

If, however, the telescope has to fulfil certain complicated requirements, like one of the most modern type of gun sights, which need a large number of optical elements in their construction, the amount of light lost increases alarmingly. Take the case of the gun sight such as shown in the accompanying illustration, Fig. 1, which represents a type in fairly common use. In this instrument

the line of sight undergoes two rectangular changes by means of prisms Nos. 2 and 5. Lens No. 1 is the objective; No. 3 is a lens for regulating the oblique rays, No. 4 the glass plate having engraved on it the cross lines; Nos. 6 and 7 constitute the erecting system, Nos. 8 and 9 the eye-piece proper. I have placed beside each element its corresponding transmission coefficient. The prisms usually are silvered, as moisture condensing on the back would interfere with total reflection, and it has to be a very good

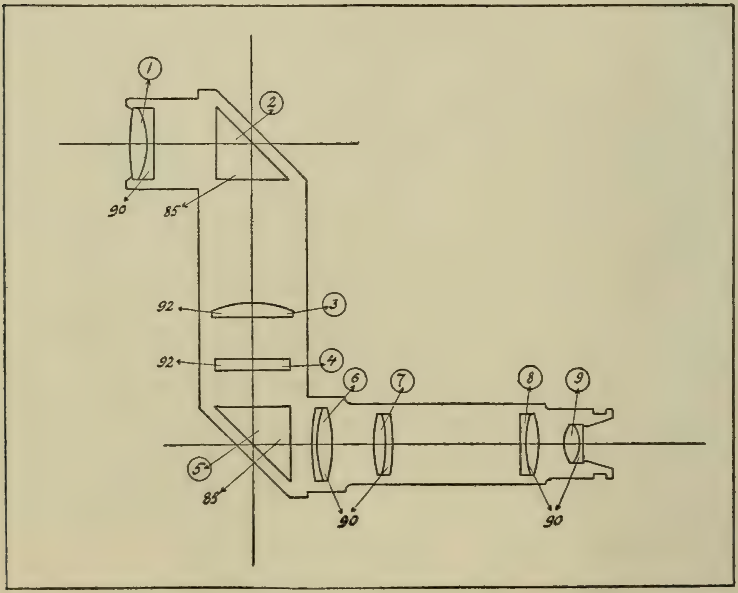


Fig. 1.

silver coating that yields a prism with a higher transmission than 85 per cent. Multiplying all these coefficients there is obtained for the total transmission 36.2 per cent., and this figure, when considering the absorption of about 3½ inches (8.89 cm.) of glass for the combined thickness of prisms and lenses, actually becomes only 32.5 per cent. And in some of the modern periscopes for submarines, especially those in which the eye-piece is stationary whilst the head prism only revolves to sweep the horizon, so many optical elements are employed that barely 20 per cent. of the light reaches the observer.

In view of the importance which submarines have recently acquired in warfare, it may not be amiss to describe briefly the construction of a periscope. Roughly speaking, the object of a periscope is to produce a large field of view through a long, narrow tube at comparatively low magnification. It would be obviously impossible to construct a periscope on the principles of an ordinary astronomical or terrestrial telescope, as the lenses would assume enormous dimensions if a large field of view were required. One has therefore had recourse to a very simple but efficient plan. As you probably all know, the principle of a telescope is to take an object appearing from the point of vision under a narrow angular view, and produce it to the eye under a wide angle. The quotient of these two angles constitutes the magnification of the telescope. Now, if we look through a telescope in the reverse direction, that is, through the objective lens, our telescope would show objects that really appear under a large angle reduced to a small angle to the eye. Thus, by taking two telescopes of the same magnification and placing them with the objectives facing one another, the first telescope will take a large angle of view and reduce it to a narrow one; and the second telescope will receive this narrow angle and widen it out again to the wide angle originally received by the first telescope. This is the principle of construction of a submarine periscope. In the illustration (Fig. 2) I am showing the optical construction of the simplest form of periscope at present in use. Leaving aside the prisms, which only serve to deflect the line of sight from horizontal to vertical and again to horizontal direction, the upper or reducing telescope would be composed of the elements C, D, E, F and G, in which C and D, in combination, constitute the eye-piece, F and G, in

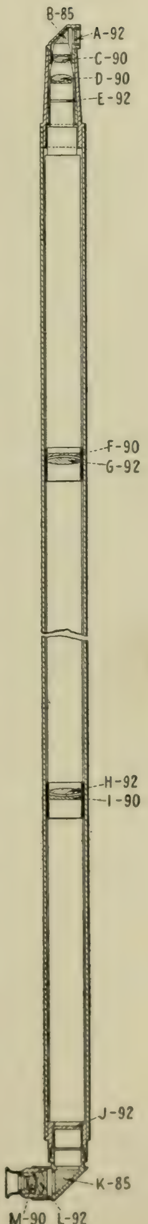


Fig. 2.

combination, the objective. E is a ruled glass plate serving as a telemeter and placed in the joint focus of objective and eye-piece. This telescope reduces the large angle of the field of view to one about fifteen to twenty-five times smaller. This narrow angle easily goes through the long, narrow tube of the periscope—I may remark here that the standard dimensions of a periscope such as used by the United States Navy at the present time are: length about 22 feet (6.70 m.), diameter of tube 5 to 6 inches (12.7 to 15.24 cm.), tapering at the head to about 2½ inches (6.35 cm.)—and the lower telescope, which consists of the objective combination H and I and the eye-piece combination L and M, receives this narrow angle and again widens it out and presents it to the eye of the observer as the same as, or even larger than originally seen through the upper telescope. The plate A serves as a protection to the head of the whole instrument and the plate J acts as additional protection in case a gun shot or collision should damage the projecting part of the tube, so that not water can enter the boat. I have affixed to the letters the respective transmission coefficient of each optical element; multiplying all these, we find that the periscope can transmit only about 25 per cent. of the light originally received, and if we take into further consideration the very considerable thickness, in the aggregate, of all the optical elements, we find that this in turn produces a further loss of 23 per cent. approximately. Thus, the total amount of light received by the observer's eye would only be about 19 per cent. of the original amount received by the periscope, and it is easily seen that any process which can lessen the loss of light would constitute a great advantage.

And the actual loss of light by reflection is not the only drawback. There is in addition a loss of brilliancy and contrast in the image which is quite appreciable. The cause for this is light which has undergone two or four reflections from the glass surfaces. It is easily seen that light reflected from the second surface of the first lens will return again towards the source whence it came, but in doing so it will strike the first surface of the lens and some of it will again be reflected towards the observer. Similarly, light reflected back from the first surface of prism No. 2 will hit the back of objective No. 1 and part of it will be sent back towards the observer, while the remainder will impinge upon

the front surface of objective No. 1; and part of that again will be reflected back into the observer's eye, and so on all through the system. Now all this doubly reflected light does not contribute anything to the brightness of the picture, for it does not come to focus at the proper point, but has its own focal points, and is out of focus at the place where the true image lies. It therefore forms a veil of stray light over the picture which detracts from its brilliancy.

It would thus be a most desirable thing if it were possible to affect the glass surfaces in such a way as to reduce the amount of reflection. Curiously enough, it has been known for some time that it is possible to *increase* the reflecting power of a surface. Prof. Wood, of Johns Hopkins University, some years ago made the remarkable discovery that by coating a glass surface with a thin solution of commercial collodium a degree of reflection could be obtained quite out of proportion to the refractive indices of either the glass or the collodium itself. In fact, the intensity of reflection was such as would correspond to a refractive index of 1.96 while that of collodium is only 1.48. He explains this as possibly being due to a surface strain, and this explanation of his is borne out apparently by some very interesting experiments conducted by Lummer and Sorge in 1910. These two experimenters were studying elliptical polarization on glass prisms. Theoretically speaking, a glass plate inclined under an angle of 45° should reflect plane polarized light again as plane polarized, but this hardly ever occurs; almost invariably the light is elliptically polarized. Lord Rayleigh and others attributed this change in the light vibrations to a surface film and strengthened their explanation by the fact that a freshly broken crystal surface or a perfectly clean glass plate shows no such effect, and in further investigation of this subject Drude computed the thickness of this surface film to be less than 1/200 of a wave-length. Lummer and Sorge, however, took some prisms that showed distinctly elliptical polarization and rubbed, not the reflecting surfaces, but the bases and found that by doing so they could make the polarizing effect disappear. Apparently, therefore, they released by this rubbing a very slight surface strain in the reflecting surfaces. Now it may be possible that this surface strain is responsible for the reflection of some of the light that impinges upon the surface

and it might even be of commercial value to investigate this matter, as the reflecting power plays a very important part in all cut glass work and glass shades for illuminating purposes.

For optical work, however, just the opposite is desired, *viz.*, the lessening of the reflecting power and here, as is very often the case, chance has given us a hint which has already produced very desirable results. In 1904 Harold Dennis Taylor, the well known English lens expert and designer of the Cooke lens, saw a very badly oxidized photographic lens which had been returned to be repolished. Possibly just to find out how much light was lost through this oxidation he exposed two plates under identical conditions, one through a perfectly new untarnished lens and the other through this badly oxidized specimen. To his great surprise he found that the plate taken with the badly tarnished lens had received considerably more light than that taken with the new lens, and being one of those careful experimenters who take advantage of every hint of that nature and utilize it as a basis of new experiments, he sought means to oxidize lenses artificially and tested their light transmitting power. He soon found some chemicals which would attack at least some of the glasses used in optical instruments, particularly the barium crown which is practically indispensable in high grade photographic anastigmats. His treatment consists in immersing the lens immediately after polishing for a short time in an aqueous solution of ammonia and sulphureted hydrogen. The lens then assumes at first a brownish, later a blue tinge; in places where it was not quite clean it becomes iridescent; if the treatment is carried too far it turns a golden red.

Acting upon the hints contained in Mr. Taylor's description I have during the last two years, experimented a good deal with different chemicals along the same lines and have found means of oxidizing most of the glasses used in optical work, particularly all barium crowns and flint glasses. The only glass I have not been able to affect yet is the boro-silicate crown which is used for prisms; but nearly all crown glasses, excepting those containing barium, are exceedingly refractory in treatment.

I have here a number of disks all made of identically the same glass, a barium crown of refracting index of about 1.6. Each one of the disks should, according to the Fresnel formula, transmit 89

per cent. of light. Disk No. 1 is absolutely untreated and you will find if you examine it through this photometer that it actually transmits this amount. Disk No. 2 has been treated twenty seconds; No. 3, 40 seconds; No. 4, 60 seconds; No. 5, 80 seconds; if you will examine these through the photometer you will find that the transmission increases steadily until it reaches a maximum of about 96 per cent. for disk No. 4. Longer treatment decreases its transmitting power again. I have here, furthermore, a number of flint disks similarly treated. In almost every one of them the transmission coefficient is over 95 per cent. and I have a small tube here in which we can mount four of them in series and you will see that the transmission of the whole instrument is considerably higher than 69 per cent., the amount which we found previously to be the maximum obtainable in an astronomical telescope consisting of four elements.

The difference in reflecting power is so considerable that it is actually not necessary to use the photometer. If I let the rays of a bright light fall upon one treated and one untreated glass plate lying side by side you will see two reflections against the ceiling and even the unaided eye at once perceives the difference in the brightness of the reflection. But the photometer shows us that the amount of light taken away from the reflected part is actually not absorbed by roughness of the surface but added to the transmitted part.

If I am asked to give an explanation for this remarkable fact I must frankly confess that I have several, but am not sure which one is correct. If reflection is due to a surface strain, then possibly the chemicals which have dissolved the glass at the surface have broken up such strain. On the other hand, it is possible that the surface has been broken up into irregularities of exceedingly small size, too small, in fact, to affect light waves sufficiently to reflect them.

Another explanation, and to me the most probable one, would be that the chemical treatment forms at the surface a vitreous compound having a refractive index considerably lighter than that of the glass itself. Assuming for instance, that such a layer exists and that it has a refractive index of 1.3, while the glass itself has an index of 1.6, the loss of light by reflection from the

vitreous layer is computed to be 1.7 per cent. and on the boundary surface between the glass proper and the supposed vitreous layer, 1.1 per cent. The total transmission of a thus constituted surface would therefore be 97.2 per cent., as against 94.7 per cent. in an untreated surface.

We are here face to face with one of the most interesting and least investigated groups of phenomena in science; that of molecular conditions at a surface. The trouble which such conditions give us in all kinds of technical work is well known. For instance, in chemically silvering glass we know that the glass surface must be absolutely clean. We clean it with water, alcohol, ether, and feel convinced that it is now absolutely clean; yet, when it comes out of the silvering bath we find that the silver has not attached itself to the glass at all but that there has been some film still adhering to the surface. We clean it again, this time with potash, tin oxide, tin chloride, or French chalk, and we find on pouring water over it, that certain parts will not allow the water to stand on them but have a greasy appearance which we can only remove after constantly repeated trials. And even then the silver film very often does not stick firmly to the glass in all cases. Another instance I would cite occurs in certain interference phenomena which can only be produced if the surface of the glass is previously coated with gelatin which must be allowed to harden and is then pulled off. Apparently this is the only means of obtaining an absolutely clean surface.

It is very much to be desired that some experimenter with plenty of leisure and skill should make a special study of surface phenomena; in my opinion there is no doubt he may reap a rich harvest.

DISCUSSION.

PROF. RUSSELL: I was especially interested in Mr. Kollmorgen's paper. In the first place, I want to most heartily congratulate Mr. Kollmorgen both on the very important results he has got, and on his exceedingly clear and interesting manner of presentation, which I have never heard surpassed, and rarely heard equalled. Also the results which Mr. Kollmorgen has got are of very great importance. I cannot help saying a few

things about it from the point of view of the astronomer. Of course we have the advantage, as Mr. Kollmorgen expressed it, of working with relatively simple optical instruments; but even with the simplest instruments, these things are extremely important to us. For example, take this question of the flare spots. They are familiar to astronomers and I think I am hardly telling tales out of school if I remark that cases have been known where the discovery of faint companions near bright stars, or even of a faint satellite of some planet, have been seriously reported, when after investigation it was discovered that they were only these reflection images produced in such a way and under such circumstances that their appearance might "deceive the very elect." Sometimes they only appear when we get the thing centered. It is a difficult problem for the trained observer to be quite sure that the things he observes are really there in the sky, and if Mr. Kollmorgen would be able to supply us with eye pieces in which these most troublesome reflections are diminished, it would be of great service.

Another matter of great importance is in more complicated instruments, at the other end of the telescope—the eye end, which you might really call the business end, the one the astronomer is most intimately connected with. I think of an instrument, a photometer, which has in succession an achromatic prism, a double image prism, a Nicol prism, and an ordinary eye-piece. Now, there we get a very considerable loss of light, and we do not like this at all. Anything that will save us loss of light right there will be of very material value to us in our actual work at Princeton. In several of the great observatories there are being used photographic spectroscopes in which the stars' light passes through a train of prisms, and the resulting spectrum is photographed. Now, the reflection losses in that case are very serious. The loss is somewhat diminished by using certain properties of polarized light. One of the two polarized beams is transmitted and the other is partially reflected, and the first couple of prisms do almost all the reflection, so that the rest behave as if they were beautifully transparent. Even so, I believe that if Mr. Kollmorgen will be prepared to take our prisms and objectives and treat them in order to make them more

transparent, he will perform for the workers a very considerable service, even though the percentage gain in exposure does not seem to amount to very much, for astronomical exposures are often several hours long. When one sits around for about eight hours with an eye glued to the eye-piece of the small guiding telescope, which is assuring one that the clock work of the main instrument is continually working properly, a 10 per cent. shortening of that exposure will be a very considerable boon, and if Mr. Kollmorgen can only do any such thing for us, I can be sure the astronomers will rise up and call him blessed.

Mr. G. H. Stickney: Is the saving of light in the lens system of a stereopticon lantern likely important? Assuming four condenser lens surfaces and four to eight objective lens surfaces, about what will the difference amount to?

Dr. Louis Bell: This paper of Mr. Kollmorgen is of great theoretical and practical interest, first as representing a real advance in the practical transmitting power of optical instruments, and also as raising some questions of profound interest regarding the cause of the decreased surface refraction. From the physical standpoint I am inclined to think that Mr. Kollmorgen's suggestion of a vitreous surface layer of low index of refraction meets the available facts more closely than any other. The heavy flint glasses which yield most readily to the new treatment are practically lead silicates with some fluxes and perhaps an excess of silica borne in solid solution, more than half the entire weight of the glass being in the form of PbO. Oxidation and perhaps other active chemical treatments of the surface might very well set free either directly from solution or by decomposition a tenuous surface layer of practically pure silica, which in some of its forms, there is reason to believe, may have a very low refractive index. The old familiar list of substances arranged in order for a refractive index begins with tabasheer, determined by Sir David Brewster more than 100 years ago, as having a very low index of refraction, something below 1.2. This substance is practically a deposit of pure silica found in bamboo joints, and conceivably silica otherwise deposited might have a similar index which is low enough to account for the very beautiful phenomena which Mr. Kollmorgen has disclosed. This explanation too

would account for the difficulty in dealing with crown glasses, particularly boro-silicates which are free from the comparatively easily attacked lead silicate found in the flint glasses.

(Communicated after adjournment): On looking up Brewster's value for the refractive index of tabasheer which, if I remember correctly, was determined by the polarization angle which turns out to be 1.11 for your light. The only other determination which I have been able to find reference is a comparatively recent one of the index tabasheer saturated with turpentine apparently for the purpose of making it transparent so that a prism could be used. This was about 1.46, in other words nearly the index of turpentine itself. In view of the present issue it would be interesting for someone to find out whether Brewster may not after all, working as he did on a method which depends on a surface layer, have been right in his estimate. If so the theory would indicate that we might have to look still deeper into the nature of the surface phenomena to account for the extremely low figure.

Mr. M. Luckiesh: I am exceedingly interested in Mr. Kollmorgen's paper which is indeed a welcome addition to our Transactions. I am interested especially from the standpoint of one who uses instruments such as the spectrophotometer and spectrograph in which scattered light is a nuisance. While in such instruments it will be gratifying to conserve the light by the application of Mr. Kollmorgen's process, in many cases the loss of light is not of the greatest importance. What becomes of the light that is "lost" by reflection from the optical surfaces is often of chief interest. This light is scattered about in the instrument and often vitiates the results unless extreme care is taken to avoid it. When examining the weaker portions of spectra the scattered light is sometimes a great proportion of the total light visible. In some cases colored filters, diaphragms, etc., can be employed to advantage in eliminating most of the scattered light but Mr. Kollmorgen's interesting paper indicates that he is able to be of great assistance in improving such instruments as the spectrophotometer.

MR. F. L. G. KOLLMORGEN: If you will permit me I will answer these questions in their reverse order beginning with the one about moisture in periscopes. This is one of the most difficult points to overcome. Even the slightest amount of moisture contained in the air within the periscope is liable to give a great deal of trouble, for it will condense on one of the lenses and fog up the vision completely. The plan now generally adopted is to fill the periscope in the factory with carefully filtered dry air, then seal them hermetically and instal them in the boats and trust to Providence that they will keep water tight.

I am not sure whether the reflection in spectacle glasses can be appreciably improved by chemical treatment. To begin with, spectacle lenses are always made of crown glass which does not lend itself very satisfactorily to the treatment, and further, the total amount of reflection in one spectacle lens is only about 8 per cent., and if we succeed in reducing that from 8 to 4 there would still be some reflection present to which the wearer might object.

Mr. Luckiesh asked about treating photographic plates with an idea of killing the halation effect which is nothing but the reflection from the uncoated side. Here we have already a very simple and inexpensive remedy at hand in the so-called backing of the plates which consists in coating them with a quick drying solution having approximately the same refractive index as glass. It would therefore not seem worth while to subject the glass plates to a chemical treatment which would necessarily be more expensive and probably less effective than the ordinary coating.

I was very much interested in Dr. Bell's remarks. He mentioned tabasheer as standing at the head of Dr. Brewster's venerable table of refractive indices, and also solved for me a mystery of many years standing by telling us that tabasheer was a form of silica found only in bamboo joints. For many years I had known the name of tabasheer without ever associating any meaning with it. Dr. Bell suggests that possibly the chemical treatment changes the silica contained in the glass into a form similar to this tabasheer which according to Brewster has the lowest refractive index of all substances known. I must say that this seems to me a very probable explanation.

To come now to Prof. Russell's query about the application of chemical treatment to astronomical instruments particularly spectrometers and spectrophotometers. It seems to me that in instruments of this kind containing large quantities of optical elements such as prisms and lenses the treatment should yield very appreciable results. All the prisms are usually made of flint glass and would take the treatment very successfully, and so will a large number of the lenses and as we have to deal in the observation through such instruments with light of exceedingly feeble intensity anything that will give more light through the instrument does constitute a great improvement.

Prof. Russell mentioned furthermore, the stray figures sometimes appearing in a telescope which are due to reflection and which are often misleading to an amateur and sometimes even to an experienced observer. This recalls to me a very interesting little book which I had in my library for many years until I loaned it to a good friend. I have it no longer. This book was written by an English surgeon, a Dr. Kitchener, in 1797, and was entitled, I believe, "The Telescope, A Guide Book for Amateurs." The author speaks of internal reflections and mentions a letter which some one had written to the *Times* about the planet Jupiter having suddenly developed a curious sickle shaped excresence. Needless to say the planet Jupiter had not been guilty of any such eccentricity; it was simply a defective objective or an interior reflection that had produced this peculiar appearance. Incidentally, as a matter of curiosity, I would mention here that Dr. Kitchener speaks in almost every page of his book of his three and three quarter inch triple objective made by Dollond which appears to have been a very fine glass. He is so enthusiastic about it that several times he states that this objective "Will probably never be surpassed even if equalled, as all glass makers have assured me that it is impossible to obtain a piece of glass larger than three and three quarter inches sufficiently homogeneous for astronomical purposes." We wonder what the good Dr. Kitchener would say to the thirty-six and forty-inch objectives of our time?

Finally as regards chemical treatment of the lenses in a projection lantern: I doubt whether that would be worth while; we have usually such a large amount of light available that it hardly

seems necessary to increase the light transmission. But it has been shown that the more glass thickness we have in a projection lens, the less heat will reach the slide or film; it might, therefore, possibly be of advantage to introduce a number of glass plates with a view to reducing the heat transmitted and then treat these glass surfaces chemically to restore the light transmission.

THE LIGHTING OF SHIPS.*

BY H. A. HORNOR.

Synopsis: This paper outlines the lighting requirements of commercial and naval vessels, and briefly discusses systems of distribution, plants, fixtures, signal lighting, and searchlights.

The vitiation of air on vessels when the hatches are battened down during bad weather, the reduction of fire risk, the ease of distribution, the convenience of control and general reliability are factors which contribute to the use of electricity for the power supply for lighting ships. An acetylene system of lighting similar to that installed on automobiles has been developed for small motor boats and yachts, but the application has not been applied to larger craft. As an auxiliary to the required signal lights, oil lanterns are kept in readiness and in some instances combined oil and electric running lamps are installed. Inventive skill might devise a simple and reliable combined lamp that would automatically light in case of failure of the electric lamp. It may be of interest to note that, although an extensive system of temporary electric lighting is usually used during the construction of a steel vessel, a large number of candles[1] is also employed. The number of candles, of course, varies in direct ratio with the number of ships building; the average approximates 100,000 a year for a large and busy shipyard. It is not the purpose of this paper to consider the lighting of vessels during construction, that is a problem in itself, but attention may well be directed towards this question. A passing idea of its extent is indicated by the fact that approximately 80,000 incandescent lamps are used per year for construction work. As electricity is universally employed for the lighting of steam vessels, such an installation will be described.

* A paper presented at the ninth annual convention of the Illuminating Engineering Society, Washington, D. C., September 20-23, 1915.

[1] Ferry boats of the Pennsylvania R. R. plying between Philadelphia and Camden, N. J. carry permanently mounted candle lamps for emergency purposes.

INSTALLATION AND DISTRIBUTION.

Certain rules, as in land practise, are laid down for the marine installation. These requirements are contained in the code of the underwriting society under whose classification the entire vessel is constructed, in the regulations of the government under whose flag the vessel receives its protection, and in the specifications of the owner prepared for the purpose of guiding the builder in the specific details appertaining to the practise or trade of the shipper. Although these rules and regulations are revised from time to time, new installations generally exceed the requirements both in materials and workmanship.

The two-wire system of distribution is generally adopted in merchant vessel practise in this country. Trans-atlantic and trans-pacific vessels have not for many years been built here; and the traveling distances of small freight and coastwise freight and passenger vessels are such as not to warrant the economy of the three-wire system. Our navy has adopted the three-wire generator, but not the three-wire distribution. The two wires of a circuit are led as feeders from the main switchboard and proceed either to centers of distribution, or are tapped by mains from which extend the branches to groups of small incandescent lamps. These two methods of physical distribution are retained because the peculiar structure of a ship does not always allow of the use of only one method. Certain circuits, such as the searchlight, are required to be continuous from the switchboard to the control switch located in close proximity to the projector. Branch leads to a group of lamps are protected by fuses where the size of the wire is reduced; and for the convenience of repair the centers of distribution are usually provided with switches and fuses on each branch circuit. In the ordinary freight vessel the circuits are run in the most direct path and feed the crew spaces and officers' staterooms indiscriminately; but on passenger vessels either special distribution is arranged for the passengers' staterooms or the lamps in such rooms are taken from two independent feeders so that the passengers may not at any time be affected by the failure of light.

The owners are careful to specify a high grade of rubber covered wires, usually in excess of the requirements, and all wires

except No. 14 and No. 12 B. & S. are required to be stranded. Stranding is a necessity, due to the close fitting of the conductors to the steel structure, if they are installed without metallic protection, or for "pulling in" when encased in conduits. No wire smaller than No. 14 B. & S. is permitted except in fixture wiring and this size is commonly used for branch circuits. Twin conductors are not common in the merchant service, but are used in sizes up to 60,000 cm. in navy practise. Merchant vessels at present are equipped with a combination system of wooden mouldings and conduits for the protection of the conductors—the former used in the non-water-tight sections of the vessel and the latter in those places exposed to water, sea air, steam or other vapors. The navy has recently adopted a lead-covered, steel armored conductor which has superseded conduits and the influence of this change is already being felt in merchant practise. The chemical problem of the effect of salt air and salt water upon the materials used in the electrical equipment cannot be said to be finally and completely solved, but there are available practical means of protecting electrical apparatus and appliances. All appliances such as junction boxes, switches, receptacles, distribution cabinets, etc., which are in any way subject to the effect of hydroscopic changes, or exposures to salt air, or liable to mechanical injury are made thoroughly water-tight. The covers of such appliances, which in the main are made of brass composition, are secured by compression on rubber gaskets and the interiors of the boxes are usually painted well with several coats of insulating composition before the interior fitting is put in place. Every precaution and exacting care are taken in this regard and often, as in other matters, the cure is worse than the disease; for it may happen that by too much water-tighting, condensation results. This is not so aggravating in the case of steel-armored conductors, for then only the appliances can be the cause of trouble; but in the case of conduits the trouble has no end but one—the destruction of the rubber covered wire and the removal of the entire section which has occasioned the trouble.

GENERATING PLANT.

Generating sets range from 1 kilowatt used on small motor boats to 300 kilowatts used on battleships. For the merchant

vessel the prime mover is usually a steam vertical reciprocating engine. This engine is mounted on the same bed-plate and directly connected to the generator. Every provision in the way of ruggedness of construction, automatic lubrication, and non-corrosive parts enters the design of these sets so that reliability will result. However, these sets are usually carried in duplicate; and in some cases two sets, one small and one large, are installed to take care of the day and night load. The machinery spaces being below the light load water line are always in darkness. The law requires an auxiliary source of power for providing an emergency lighting system and for the operation of the wireless equipment on merchant passenger vessels. Special permission is granted for carrying sufficient gasoline for this purpose if desired. The steam turbine has been developed as a prime mover but opinions of owners differ as to its use. Geared turbines have not yet been given a trial in merchant service and the larger units now built for the navy have only passed their shop tests, so that this development can receive no definite comment. It can be foreseen that probably weight and economy of operation will result from service trials, if the high speed turbine and the reduction gear can withstand the vibrations inherent in a ship structure when under way. The generators are two-wire, compound-wound for a standard voltage in merchant work of 120 volts, direct current. The navy, as stated above, has now adopted a three-wire, 240-volt generator although permitting a two-wire generator with the addition of external balancers for producing a neutral lead for 120 volts. This is necessitated by the lighting and searchlights. The three-wire generators are equipped with an external compensator or stationary balance coils so connected through collector rings on the armature that 120 volts is generated between either of the outside wires and the neutral. This compensator takes care of any unbalanced currents in the neutral. The neutral is taken to the main distribution switchboard and then the feeders are led off from a two-wire bus. In navy practise switchboards are constructed of a special moisture and heat-resisting composition, and special bus-bars are arranged for the separation of the lighting and power systems. All the apparatus mounted on the board must con-

form to special government specifications. The switchboards for merchant practise are usually made of slate and the connections differ due to the owner's wish to run the generators in parallel or separately. In the latter case separate bus bars are provided for each generator and double-throw switches are installed so that the load may be arbitrarily divided. This method of connection by doing away with the equalizer lead averts the accidental running of one of the generators as a motor, an accident that may have serious results.

SEARCHLIGHTS.

The importance of the searchlights both for merchant and naval vessels is very great; consequently the development in the last few years has tended to improvements of much value. Naturally the naval projector is receiving the most attention, but the influence of improvements will redound to the advantage of merchant vessel type. The old method of magnet feed for controlling the burning of the carbons has now been superseded by the motor-operated lamp which seems destined to hold a strong place in service. The most radical departures with most remarkable results are found in the Beck searchlight a full and very interesting description of which may be found in the February, 1915, *Proceedings* of the American Institute of Electrical Engineers. The intensity of the carbon crater has been greatly increased by the use of a very small carbon pencil, by the impregnation of the carbon with rare metals, and the use of a gas to form a curtain to protect the carbon and increase its life. The paper above referred to gives an interesting series of curves showing the increase in illumination of this lamp over the old type navy projector. The standard size of searchlights now used on battleships is 36-in. (0.9 m.); smaller naval vessels are equipped with 30-in. (0.76 m.) and 24-in. (0.6 m.) projectors. Battleships are also provided with a small 12-in (0.3 m.) signalling projector. Some of the 36-in. projectors are designed for portability about the deck and are mounted on a truck equipped with a remote electrical control and portable connections. The merchant service uses searchlights for sighting buoys when coming into harbors at night and at times for loading or getting away from the dock. For a vessel of any great size or length

the smallest searchlight of any advantage is the 18-in. The merchant projector carries only a plain front glass except for vessels plying through the Suez Canal; on these vessels a diverging lens is placed on the searchlight barrel so that the light may flood each bank of the canal and cast a dark shadow in the middle of the canal so as not to interrupt the up and down traffic. The navy employs shutters both of the iris and venetian blind type for signalling purposes.

RUNNING LIGHTS AND NIGHT SIGNALLING.

The lights required by law when the vessel is underway at night are the masthead (white), the port (red), the starboard (green), the range (white), and the stern (white). All these lanterns are fitted with Fresnel lenses and screened to conform to the law. The masthead light is constructed to illuminate an arc of the horizon of 20 points of the compass and so located as to throw the light ten points on each side of the vessel; that is, from dead ahead to two points abaft the beam on either side. It must be visible for a distance of at least 5 miles (8.04 km.). The port and starboard lights operate over an arc of the horizon of ten points of the compass and are so arranged that they may be seen directly ahead and two points abaft the beam. They are so screened that the light may not be seen across the bow. They must be visible at a distance of at least two miles (3.21 km.). The masthead light is carried on the foremast and the range light, which is similar in construction except that it must be fixed to throw the light around the horizon and be visible at a distance of at least 3 miles, is located 15 ft. (4.57 m.) above the masthead light on the mainmast. The stern light is also similar in construction to the masthead light but the light must not be visible forward of the beam. Vessels towing another craft are required to exhibit forward in a vertical line with the masthead light two lights, similar in every respect to the masthead light for a short tow and three lights for a long tow. These lights are spaced about 6 ft. (1.82 m.) apart. A vessel over 150 ft. (45.72 m.) long is required to show a white light both forward and aft visible all around the horizon for at least one mile (1.60 km.) when the vessel is at anchor. If an accident occurs so that the vessel is not under command, the vessel must

carry in lieu of her masthead light at about the same location and approximately 6 ft. (1.82 m.) apart two red lights visible all around the horizon for a distance of at least 2 miles (3.21 km.). If the vessel is engaged in some work such as laying or picking up submarine telegraph cables it must in the same manner exhibit three lights in a vertical line, the highest and lowest of these lights being red and the middle white. Such a vessel if not under way must extinguish her side lights. In order to attract attention a vessel may use a flare-up light that cannot be taken for a distress signal.

The distress signals are as follows. The production of flames from anything such as a burning tar barrel, oil barrel, etc., and "rockets or shells throwing stars of any color or description, fired one at a time at short intervals."

As an aid to navigation not required by law and not necessarily the practise, a small light is placed on the forward flag staff and so shielded that it becomes but a point of light; with this the helmsman can then point to any range light or other visible object.

Private signal lights for a fleet of vessels or naval vessels are permitted, so long as they are registered and not used to confuse the regulation lights.[2] Naval vessels carry lanterns on the extreme peak of the mast, called trucks. These truck lanterns consist of double white and red lenses and the lights are electrically controlled from the bridge. Hand and automatic signals can be given and a code used. Again certain naval vessels carry what are called "blinker lights"—white lights placed on the ends of the foremast yard arm and used for close communications between vessels when in maneuvers. Portable "blinker lights" are designed in the form of a telescope and may be used by the officers of the vessel in a similar manner. A white lantern is also mounted abaft the after funnel and its light is similarly controlled from the bridge. Flag ships carry a string of vertical lights usually suspended from the after mast. When lighted in specific routine, they indicate whether or not the admiral or captain is aboard. Naval vessels are also equipped with a night

[2] Merchant vessels now carry a single white light on the navigating bridge equipped with a Morse telegraph key so that private code signals may be given.

signalling set which consists of a vertical ladder suspended from both the fore and mainmast containing four lanterns with double lenses, one white and one red. Each lantern contains from six to eight small incandescent lamps and these are controlled by what is known as a keyboard. This keyboard resembles a typewriter keyboard whence it has received its name. By depressing the keys certain combinations of the lights follow and in this manner a complete alphabetical signalling system is established. Semaphores located on the bridges are also illuminated with different colored electric lamps and operate on the "wig-wag" system in the same way as by day.

FIXTURES.

Those fixtures which are exposed to steam vapor in the machinery spaces, located on the weather deck which is continually subjected to salt air, and intermittently exposed to the swash of the sea, are carefully made water-tight. The conductors are led into a box in which a lamp socket of the screw type is secured. This metal box is arranged with a coarse thread into which is screwed the glass globe and made only large enough to contain the ordinary pear-shaped incandescent lamp. Where severe mechanical injury may be expected, a guard is placed over the globe. Several types of such fixtures are designed for ease and convenience of installation. A fixture located in a vertical position is called a deck or drop fixture; or, if the fixture has a bracket cast on a base, it is called a bulkhead fixture. Following the same general principles of construction, fixtures are designed for installing the larger lamps. In the merchant service the globes are all of clear glass, but on naval vessels prismatic globes are now provided. Special blue glass globes were used on two foreign battleships recently built in this country and formed a separate circuit for use during battle; the object sought being to prevent the enemy from observing the vessel and yet provide light for the officers and crew. Such conditions are provided for in our navy by a battle circuit of yellow lights properly shaded. Battle lanterns (portables) are also so equipped. Since the important working parts of the vessel are contained behind the casemate armor, no lights would be visible to the enemy. In both ser-

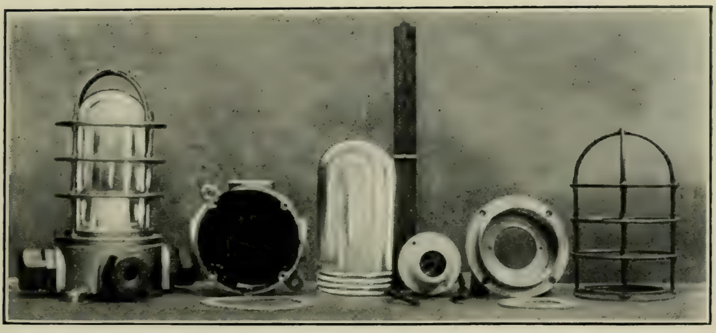


Fig. 1 (Upper).—Bracket fixture for merchant vessels. Fig. 2 (Middle).—Water-tight and non-water-tight portable units for merchant vessels. Fig. 3 (Lower).—Water and steam-tight fixture.

Fig. 4.—First-class stairway aft of machinery casing. Bridge deck.

Fig. 5.—First-class lounge. Boat deck forward.

Fig. 6.—First class lounge looking aft. Bridge deck.

Fig. 7.—Second class lounge and writing room. Bridge deck aft.

vices the metal for fixtures is preferably a brass composition, the navy type being much heavier than the merchant type. Iron boxes for the fixtures could be used in merchant work, but the economy would not be large and the weight only slightly, if at all, reduced. On naval vessels a much heavier and larger fixture is used for lighting the magazines and handling rooms. This fixture is circular in form, about 10 in. (25.4 cm.) in diameter, contains two incandescent lamps on different circuits; the lamps are protected by a piece of clear glass about 1 in. (2.54 cm.) thick; the cover is of cast brass composition made in the form of cross slats of wide spacing, but of sufficient strength to withstand severe abuse; the cover is secured to the light box by means of dogs which compress it on a rubber insertion; the interior is painted white and the back is fitted with a flat nickle reflector. Recently such a fixture was designed for a foreign navy with this change: the reflector was made as nearly as possible to the parabolic shape and the surface silvered. In service the rubber gasket immediately affected the silver mirror and next the concentration of the radiant heat from one tungsten lamp broke the front glass. Fixtures of this same general design, arranged so that the box extends through the bulkhead allowing the electrical connections to be made outside of the compartment in which the illumination is desired, are called bulkhead bunker fixtures because they are used for lighting coal bunkers. The extensive use of oil fuel on battleships and other naval vessels has greatly reduced the number of such fixtures. Fixtures resembling the regular steam-tight globe fixture are especially designed by some owners for use on oil tank vessels. The salient difference is to do away with the screwed glass globe and seal the globe onto a brass ring which is provided with a long fine thread, by means of which it is attached to the brass box forming the base of the fixture. The reason for this lies in the endeavor to preclude the entrance of oil fumes. This practise is not general.

It is not the intention to describe in detail all the fixtures used on shipboard. Those so far referred to are required by the application and should be given consideration by those who desire to interest themselves in the improvement of shipboard lighting. The fixture designer is given full sway in those portions of the

vessel where protection is assured and which are designated for the comfort, convenience, and entertainment of the passengers. Such is also the field for the application of the principles of illumination and all the art and skill of the illuminating engineer may be utilized. Every design and type of fixture may be adapted for this purpose, if so constructed that it may be mounted on a flat surface. In practise the owner, or the owner's representative, selects the fixtures, following previous installation on other vessels. The builder usually figures on such a duplication. Some owners, particularly when making a decided departure, state to the builders how much money to include in their estimate and reserve the right to add to this amount at their own cost. On large passenger steamers will be found indirect cove lighting, concealed lighting, semi-indirect, decorative and direct lighting. Although swinging fixtures cannot be used, the effects are obtained just as well with similar stationary arrangements. The fact that bad weather drives the passengers from the decks, especially in fast trans-atlantic liners, has caused the owners of such vessels to make the general gathering rooms most elaborate in both fittings, furniture and fixtures; so that with the esthetic surroundings great latitude is allowed the illuminating engineer. These remarks must not be interpreted to mean that good lighting on shipboard prevails; for, as on land, there are many examples of very poor lighting and the field is full of opportunities for marked improvement. The unshielded incandescent lamp, sometimes frosted, is still very generally employed, and this is probably due to the satisfaction that this illuminant gives by its ease of replacement and convenience of distribution.

The standard 110-volt lamp, either carbon or tungsten filament, is used exclusively. Although there has been some success in employing the tungsten lamp in machinery spaces, the vibration surrounding the propelling machinery may cause a reduction in the normal life of the lamp. The high-wattage tungsten lamp of 250 or 500 watts has taken the place formerly held by the carbon and mercury arc lamp in the lighting of large spaces in all classes of vessels. The 25-watt and 40-watt tungsten lamps are used throughout the vessel for staterooms, passageways, etc.

CONCLUSION.

In the foregoing pages an attempt has been made to describe the practical methods of the lighting of ships in this country at the present time. Mention has not been made of minor uses of light, such as the illumination of binacles, clocks, dials of interior signalling instruments, gages in the engine room, oil sights on the main propelling engines, surgical instruments, chart tables, signalling apparatus for the transmission of orders, etc. Many of these applications are of extreme interest and subject to almost endless development. The automatic lighting of life-buoys when they are cast into the sea at night is also deserving of passing notice. There are also investigations under way for the use of the selenium cell in connection with light for determining so important a factor as the quality of the smoke passing through the stack. Suggestions for the lighting of the chart table, where light is necessary, although the compartment is better maintained in darkness, include a proposal to construct the top of the chart table of clear glass and so mount the lamps that the light will be projected through the chart.

In ship lighting the illuminating engineer has a large, varied and interesting field opened before him. The work has hardly begun and will probably never end as long as men maintain their commercial intercourse and strive for a closer world family. From the fundamental quest for a cheaper, more efficient and satisfactory illuminant to the most expensive, elaborate, and luxurious application of light, the engineer finds on a vessel very nearly every problem encountered on land. Although it may be well to consider that on shipboard there are decks instead of floors, bulkheads instead of partitions, and no ceilings for they are all decks whether overhead or under foot, still light must be provided for libraries, dining rooms, kitchens (called galleys), machine shops, store rooms, ballrooms, gymnasiums, butcher shops, refrigerating plant, bedrooms, exterior spaces, indoor tennis courts, roof gardens, swimming pools, theatres, and streets (called passageways)—streets which run not only on the horizontal plane but also on the vertical and ceaselessly change their course.

Many problems remain for the photometrist and the physicist. And just as the laws of sound beneath the water have been

studied so must the laws of vision beneath the water be investigated. These men must answer such questions as: How do fish see? How do the eyes of a sea gull function so that it complacently enjoys long vision in the sky above the expanse of the sea, and at the same time is able to plunge intrepidly and surely for its prey into the water?

Prof. Blondel has made remarkable investigations on the "threshold of vision," observing with scientific patience the perception of point light sources at great distances. This subject quite closely attaches itself to the navigation of vessels and couples with it the question of color discrimination at long range. With this problem we bring to our practise the two important branches of science physiology and psychology.

DISCUSSION.

MR. L. C. PORTER: The reasons why ship lighting has been given little attention are set forth in the paper and attention is brought to the fact that it is unusual for the illuminating engineer to be able to cooperate with the architect in the designing of the ship.

The speaker had the good fortune to cooperate with an architect on the lighting of a ferryboat and also on the lighting of a river steamer, having the privilege of taking up the lighting with the construction plans of the boat. The speaker's suggestions were carried out, and we now have a ferryboat, a river steamer and a lake steamer which can be pointed to as examples of what can be done in scientific lighting. It is hoped that an ocean liner will come into this class before long. The subject is certainly receiving more attention.

On the second page Mr. Hornor mentions of the large number of lamps used for construction work. Generally these lamps are carbon lamps, because construction work is so rough that a large number of the lamps are broken; that is, the bulbs are mechanically smashed before they have anywhere near burned their total life.

On the fourth page mention is made of the use of emergency batteries. The introduction of the mazda lamp was a great boon to the use of batteries; it meant considerably less weight in bat-

teries, and for new vessels it means less weight in the generating equipment and smaller space, and that is of vital importance in a ship, because the more space that can be given up to fuel storage, the greater will be the range of the vessel. There are also several other advantages.

It is interesting to know that incandescent searchlights have been developed of a type which are effective up to half a mile. These find considerable application, particularly in the merchant service. Their control, maintenance and upkeep is much simpler than that of the arc, which should be an advantage to merchant vessels.

On the sixth page, in reference to the signal lamp, it is interesting to note that tests have shown that one can see a 5-candle-power lamp in a small reflector at a distance of 20 miles, without the use of glasses. Blondel speaks of colors. The speaker has been able to distinguish without glasses red and green, at that distance. One advantage in the use of a small filament tungsten lamp in a parabolic reflector which, when directed at the other ship or party to which one is signaling, is that the signal can be read easily over great distances if the beam is trained directly at the receiving station, while others a little out of the direct line the beam cannot see the light. That makes a more or less secret method of signaling at night.

The reason flood lighting units should find considerable application for loading vessels and coaling is that for this work it is desirable to cover a fairly large area on the barge from which the coal is being loaded and on the deck of the ship where it is being lowered through the hatchways. Flood lighting units will accomplish this and can be easily located at any convenient distance.

On the thirteenth page, in reference to the high-wattage tungsten lamp, it is interesting to note that these are used largely now in fire rooms and engine rooms, particularly the 250-watt lamp. I witnessed some changes on one of the battle ships in which the old sixty-four watt carbon lamps stuck around the engine room in various places were replaced by several 250-watt mazda lamps, and the effect was that the painters immediately began painting up some spaces over in the corners which they had not

been able to see before; and they found considerable dirt, too, that the other lamps had not shown up. This brings out the point that the large lamps around machinery, throwing plenty of light, tend to cleanliness and keeping the machinery in better repair.

On the fourteenth page Mr. Hornor mentions glasses and chart tables lighted from below; it seems to me that frosted or opal glass would be better than clear glass.

There is just one point I overlooked. On the eleventh page, Mr. Hornor refers to the signaling of the lamps lighted from a typewriter keyboard. That is known as an Ardois set, and consists of a row of double lanterns, the upper ones red and the lower white. The reason for using the small lamps is for speed and reliability in case of lamp failure. It has been found that the filaments of large lamps would not light up and cool fast enough; therefore, a number of small lamps were used to gain speed. It has also been found that lower illumination was required in the white than in the red lantern lamp, because with both burning the glare from the white reduced the visibility of the colored lamp directly above it.

Mr. H. A. Hornor (Communicated): Naval installations of lighting systems, like all naval work, is performed under the cognizance of one of the bureaus of the navy department. In the case under discussion such work is cared for by the electrical division of the Bureau of Steam Engineering. The work is well planned ahead of time and in accordance with law must comply with the standard specifications which are in the hands of the bidder some two months before the contract is let. Without going into too much detail it may be stated in general that there are two specifications, one called detail specifications (covering the requirements of a specific vessel) and the other general standard specifications. These latter specifications are familiar to all those intimately connected with such applications. Besides this the vessels of the larger type, such as battleships, cruisers, etc., are designed by the naval constructors with especial structural provisions for the installation of the electrical conductors and the electrical apparatus. There is nothing in naval practise that can be considered in the slightest degree haphazard. This is further prevented by a very close inspection.

It may be interesting to note as regards the lighting of vessels under construction that means are now being devised for the use of tungsten lamps instead of carbon lamps. Although this service is extremely rough it is believed that with reasonable care and with no more supervision than is now employed that success may obtain.

In conclusion it should be emphasized that the electric lighting installation on merchant vessels even of the most ordinary commercial type is fully planned before the structural work on the vessel has begun. At least, this is always the case in the large shipyards and is due to the fact that there are so many other installations that the design of the fitting out of the ship could not proceed with reasonable progress if this were not done.

TRANSACTIONS

OF THE

Illuminating Engineering Society

NO. 2, 1916

PART II

Miscellaneous Notes

Council Notes.

A meeting of the Council was held February 11, 1916, in the general office of the society, 29 West 39th Street, New York, N. Y. Those present were Charles P. Steinmetz, president; H. Calvert, W. A. Durgin, C. A. B. Halvorson, Geo. A. Hoadley, Joseph D. Israel, Clarence L. Law, C. A. Littlefield, M. Luckiesh, L. B. Marks, Preston S. Millar, A. S. McAllister.

The meeting was called to order at 4.35 p. m. by President Steinmetz.

The minutes of the January meeting were approved as printed subject to correction later.

Upon recommendation of the Finance Committee, payment of vouchers Nos. 2380 to 2396, inclusive; Nos. 2398 to 2414, inclusive; and Nos. 2421 to 2424, inclusive, aggregating $969.68, was authorized.

The Board of Examiners submitted a report recommending the election and transfer of several applicants. The report was accepted. Several of these applications had been previously listed in the minutes of the Council as having been passed subject to approval of the Board of Examiners.

It was voted to have prepared a complete membership list, giving the address, occupation, etc., of each member. The list, which is to be printed in the form of our advance papers and subsequently in the TRANSACTIONS, is to have a foreword giving the scope and objects of the society, requirements of admission, etc. Before the list is compiled a communication together with a return card is to be sent to the entire membership advising that such a list is to be compiled and requesting each member to (1) give on the return card his or her entry for the membership roll, and (2) to apply immediately for transfer to grade of member in case such application is contemplated.

The Committee on Lighting Legislation submitted a written report, the substance of which was that at a meeting in Philadelphia last month an invitation was received from the Labor Commissioners of Pennsylvania and New Jersey asking the society to cooperate in the drafting of a code of lighting. After a brief discussion, the question was referred to the Committee on Lighting Legislation with power to act.

Mr. M. Luckiesh, chairman of the Committee on School Lighting, reported that the code of school lighting was nearly completed and a draft of it would soon be submitted to the Committee on Lighting Legislation for consideration.

Following is a report which was submitted by the Administrative Committee on Lectures:

The Administrative Committee on Lectures met in Philadelphia on January 31 to discuss with the representatives of the University of Pennsylvania the invitation which the university extended to the society through Dr. Steinmetz, which invitation has been referred to the Administrative Committee on Lectures.

The Committee adopted as the basis of its consideration the minutes of the organization meeting of the Committee on Lectures, in which there are set forth preliminary and tentative plans for the prospective lecture course.

After a preliminary discussion of the subject, the committee entered into a conference with a committee of six representatives of the university, and later, in company with that committee, visited the university to inspect the facilities which are available. At that time the committee was received by Provost Smith of the university.

As a result of this conference the Administrative Committee reports that the University of Pennsylvania has given every assurance of whole-hearted cooperation in the preparation for and the conduct of a lecture course; that the university is prepared through its provost and members of its faculty to participate in exercises attendant upon the course; that the university offers ample lecture-room, exhibition space and

other facilities in the Engineering Building, with alternate lecture-room facilities in other buildings, especially in the adjoining Randall Morgan Laboratory of Physics; that the university is prepared to have the lecture course presented under the joint auspices of the society and the university, and that the university concurs in the idea that the society should assume full technical and administrative charge of the lecture course.

In view, therefore, of the excellent auspices under which it will be practicable to present this course of lectures at the University of Pennsylvania, and in view of the recommendation of the Committee on Lectures that the invitation of the university be accepted by the society, the Administrative Committee on Lectures begs to recommend that the society formally accept Provost Smith's invitation, provided that satisfactory arrangements can be effected for holding the annual convention of the society in Philadelphia in conjunction with the lecture course, or in the event that a Philadelphia convention is not practicable, provided that the Council feels that satisfactory arrangements can be made for holding the convention elsewhere and the lecture course at the University of Pennsylvania.

The foregoing report was accepted.

Reports on section activities were given by Vice-presidents, W. A. Durgin (Chicago); Clarence L. Law (New York); C. A. B. Halvorson (New England); and Geo. A. Hoadley (Philadelphia).

Mr. Hoadley extended, on behalf of the Philadelphia Section Board, an invitation to the society to hold the 1916 annual convention in Philadelphia. It was resolved that this invitation be accepted and a Committee on Time and Arrangements appointed to care for the preliminary arrangements.

The following committee appointments were approved:

1916 Convention Committee: Joseph D. Israel, chairman.

Committee on Standards: A. S. McAllister.

Sub-committee on Elementary Lecture (Committee on Popular Lectures): Arthur J. Rowland, chairman.

Committee on Sustaining Membership: C. O. Bond, E. N. Wrightington, C. E. Stephens.

Administrative Committee on Lecture Course: C. E. Clewell.

Committee on Education: H. E. Clifford, H. B. Dates, A. E. Flowers, A. H. Ford, H. G. Hake, Preston S. Millar, E. B. Rowe, C. F. Scott, L. B. Spinney, A. N. Topping, W. E. Wickenden.

Mr. Clarence L. Law, secretary of the Mid-winter Convention Committee, reported that the total registration of the convention had been 336, and that 374 members and guests attended the banquet. The Council expressed its appreciation of the excellent work of the committee and especially that done by Mr. Law.

Oral reports of progress were received from the Committees on Lectures and Membership.

It was voted to have published a special number of the TRANSACTIONS (to be designated as the Edison-Decennial Number) to include the addresses presented at the opening session of the Mid-winter Convention and the banquet, the lecture on the lighting of the Panama-Pacific Exposition (illustrated by colored views) by Mr. W. D'A. Ryan, a photograph of Mr. Edison, together with a reproduction of the testimonial which he received when honorary membership was conferred upon him; and such additional matter as may be deemed desirable by the Committees on Papers and Editing and Publication.

Section Meetings.

CHICAGO SECTION

March 16, 1916, in the Commonwealth Edison Building, 125 South Clark Street.

A talk on "Latest Developments in Incandescent Lamps" by Mr. G. S. Merrill and a discussion of the subject by Mr. Preston S. Millar.

April 20—"Latest Developments in Gas Lamps."

May 18—"Relation of Illumination to Interior Architectural Effects."

June 15—"Modern Reflectors and Shades for Gas and Electric Lighting."

NEW ENGLAND SECTION

March 16, 1916, at the Engineers' Club, 2 Commonwealth Avenue. Papers: "Modern Gas Lighting" by Mr. Howard Lyon of the Welsbach Company; "Photo Studio Lighting" by Mr. R. ff. Pierce of the Welsbach Company.

April 13—Address by Dr. Charles P. Steinmetz, President of the Illuminating Engineering Society.

NEW YORK SECTION

March 14, 1916. Joint meeting with the American Society of Mechanical Engineers. Paper: "Modern Aspects of Factory Lighting and the New Code" by Prof. C. E. Clewell, and a discussion of the code from the mechanical engineer's viewpoint by L. P. Alford, Editor of the *American Machinist.* Preceding the meeting an informal dinner was held at McDonald's Restaurant which was attended by about fifty members of both societies. At the beginning of the meeting the privilege of the floor was given to First-Lieut. Boone of the First Battalion of the Naval Militia, who spoke on the necessity of enlisting the aid of engineers in the development of the Naval Militia as an important step in National protection. Attendance 240.

April 6—A lecture by Dr. Charles P. Steinmetz on "Illuminating Engineering."

May 11—A paper on office lighting.

June—A paper by Mr. Wm. Dempsey of the New York Edison Company, entitled "Street Lighting with Mazda C Lamps." This meeting is to be held outdoors and will include an inspection trip through the streets of New York.

PHILADELPHIA SECTION

March 17—Joint meeting with the Philadelphia Section of the A. I. E. E. Paper: "Engineering Training as a Business Asset" by Charles F. Scott, Professor of Electrical Engineering, Sheffield Scientific School of Yale University.

April 21—"Type C Lamps in Street Lighting" by T. J. Pace, Commercial Engineer, Westinghouse Electric & Manufacturing Company.

May 19—"Educational Aspects of Illumination" by Prof. F. K. Richtmyer, Chairman, Committee on Education, Illuminating Engineering Society.

June 16—"Artificial Lighting for a Hundred Years" by William J. Serrill, Engineer of Distribution, United Gas Improvement Company.

PITTSBURGH SECTION.

March 14, 1916. Joint meeting with Pittsburgh Section of the American Institute of Electrical Engineers. Paper: "Constant Current Systems for Street Lighting" by Mr. W. R. Woodward.

April 21—"Symposium on Interior Lighting."

TRANSACTIONS
OF THE
Illuminating Engineering Society

VOL. XI — MAY 1, 1916 — NO. 3

ARC LAMPS FOR STREET ILLUMINATION.*

C. A. B. HALVORSON, JR., S. C. ROGERS AND R. B. HUSSEY.

Synopsis: This paper discusses the subject of street lighting with special reference to the application of arc lamps. An appendix gives tabulated data on numerous street lighting installations, and the operation characteristics of several forms of arc lamps.

HISTORICAL.

The history of the electric arc began 100 years ago when Sir Humphrey Davy with a crude outfit consisting of voltaic cells and two pieces of charcoal first drew out what may be considered an electric arc. It was not until about the year 1878 that the electric arc began to be recognized in the United States as a practical source of illumination. Although arc lamps have been used for many purposes, from the very first their principal field has always been the lighting of streets, boulevards, parks and similar outdoor areas.

OPEN CARBON ARC LAMP.

The open burning carbon arc lamp was the first type to be successfully placed in operation, a short arc being drawn between two pencils of hard carbon and burning in the open air with a potential across the arc of about 50 volts. A number of these lamps were operated in series on a direct current circuit. A short carbon life of only about 10 hours, due to the rapid oxidation of the carbon, resulted in a high maintenance cost for the system, in spite of the fact that a cheap grade of carbon was used.

As a producer of light *per se* this lamp was fairly satisfactory, as it gave in its simplest form from 12 to 14 lumens per watt with a most excellent color of light; but, on the other hand, the distri-

* A paper presented at the ninth annual convention of the Illuminating Engineering Society, Washington, D. C., September 20-23, 1915.

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bution of the light was not satisfactory, a large amount of light being obstructed by the lower carbon, owing to the very short arc; so that the greatest intensity was actually obtained at about 40° to 50° from the vertical and almost no light was given out directly underneath the lamp (Fig. 1, curve A). This resulted in a dark shadow directly beneath the lamp, then a bright ring of light quickly fading away into blackness again only a short distance from the lamp.

ENCLOSED CARBON ARC LAMP.

About fifteen years later, the enclosed carbon arc lamp was placed upon the market and very quickly found favor replacing the open carbon arc lamps. By enclosing the arc in a small globe so that the supply of oxygen admitted to the arc was restricted, the oxidation of the carbon was reduced and a carbon life ten times as long as before was obtained. Instead of the ends of the

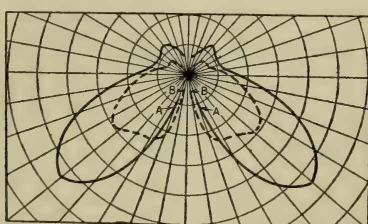


Fig. 1.—Light distribution from open and enclosed carbon arcs. A, open arc; B, enclosed arc.

carbons being pointed, they now burned off nearly flat giving a distribution of light similar in general shape to that of the former lamp though slightly modified by the different shading effect of the flat ends of the carbons (Fig. 1, curve B). The efficiency of the enclosed carbon arc was not so good as that of the open arc, but its light was steadier, the life per trim was greater and it was much more reliable and satisfactory from an operating point of view. These lamps never met with any success outside of the United States, but in this country a large number were used, probably as many as a quarter of a million burning on the streets at one period.

OPEN FLAME CARBON ARC LAMP.

It was early found in experimenting with carbon arcs that the

addition of certain alkaline earth salts would produce an arc stream of greatly increased luminosity, although little use was made of this principle until about the beginning of the present century. At first the carbons were made with a small central core which was packed with a mixture of carbon and the desired salts. Later other arrangements were tried, such as building up the carbon in three or four concentric cylinders filled with different proportions of the mineral ingredients. Another idea was to make a carbon with a star shaped section and fill the spaces between the points with a paste containing the necessary salts. These arrangements had the disadvantage that the arc would burn for a time on the salts alone giving a very bright arc, and then for a time on the carbon alone with a very much lower intensity and frequently of a different color. These different carbons have been superseded by the solid homogeneous carbon of uniform composition. Such carbons have been made to give light of various colors, but those giving white light and yellow light are the only ones which are in any sense commercial. Those giving a yellowish light are in most cases more efficient than those giving white light.

The earliest lamp of this type burned in the open air with the result that either the carbons were of excessive length or some complicated magazine arrangement was employed in order to get a satisfactory commercial life.

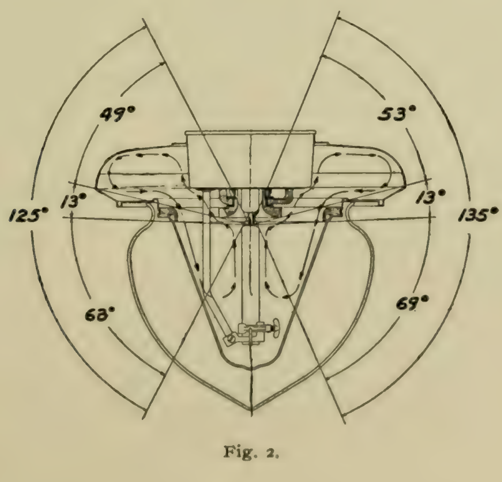


Fig. 2.

ENCLOSED FLAME CARBON ARC LAMP.

It was then found that a flame carbon arc could be operated enclosed, that is with the supply of air reduced, provided suitable arrangements were made to dispose of the solid products of combustion. Various methods were tried and adopted by different manufacturers, one of the simplest of these being that illustrated in Fig. 2. A large metal condensing chamber is provided just above the arc in which the deposit from the carbons is condensed, the heat from the arc being sufficient to keep the surface of the enclosing globe practically clear from deposit. As a general figure for comparison with other units, it may be said that the flame carbon arc will give from 40 to 70 lumens per watt, depending upon carbons, current, etc., and that these arcs may be operated on either alternating or direct current circuits. While the flame carbon arc in itself is very efficient,—in fact, it is probably the most efficient light source known at present—the requirements imposed by the economizer, the large draft space above the arc, the condensing chamber and the unavoidable deposit of fumes on the bottom of the enclosing globe, all tend to absorb light flux so that the resulting efficiency of the complete unit is considerably reduced.

MAGNETITE OR LUMINOUS ARC LAMP.

About the year 1904 there was brought out an electric arc lamp of an entirely different type. This was the so-called luminous or magnetite arc lamp. The term "magnetite arc" was early applied to this lamp because of the fact that at first a considerable quantity of magnetite, a natural oxide of iron, was used in the composition of the consuming electrode. In this luminous or magnetite arc, which has been successfully operative on direct current circuits, the positive electrode is relatively non-consuming and the light producing material is furnished by the negative electrode. In this arc, and in the flame carbon arc as well, practically all the light is emitted by the arc stream itself and little or none from the electrodes. Iron oxide, in one form or another, has been found to be the most satisfactory medium, melting as it does without decomposition and remaining a conductor at all times. Also

it is easily obtainable in a comparatively pure form. Unfortunately, however, iron oxide alone does not give an arc of high luminosity and it is necessary to add some compound of titanium to obtain a satisfactory light intensity. Chromium oxide and flux are added to steady the burning of the arc. By varying the proportions of these different ingredients, the light efficiency and consumption may be changed within wide limits and the present commercial electrodes have been developed as the best compromises of the different factors involved. For instance, it is easily possible to make an electrode that will give a burning life of eight hundred to a thousand hours, but this would not be a desirable commercial article, since central station experience has clearly shown that street lamps of every kind should be cleaned at least once a month and that the trimming of a luminous arc lamp is really only incidental to its cleaning. The efficiency of such an electrode would be low.

In the same way an electrode can be produced which will give five times this efficiency, but the life will be too short for commercial purposes.

In order to meet ordinary requirements, two electrodes have been developed and placed upon the market known as "long life" and "high efficiency" electrodes respectively. The long life electrode gives 13 lumens per watt at 4 amperes, while the high efficiency electrode gives 23 lumens per watt at the same current. Higher efficiencies are obtained at greater current strengths, the high efficiency electrode at 6.6 amperes giving about 38 lumens per watt. These figures represent the efficiencies of the arc in its simplest form and are thus comparable with the total flux efficiencies of other lamps. A metallic arc of this nature between a solid positive and a consuming negative appears in the form of an inverted cone having a highly luminous point at the surface of the cathode, when this is the lower electrode, and flaring out toward the anode. The general appearance of this arc is familiar and has been described so many times that it needs no further elaboration (Fig. 3). This light source in the form of a vertical column gives a fundamental distribution of light as shown in Fig. 4, curve A, which is the distribution curve of a 4-ampere luminous arc without equipment.

The intensity of light may be increased asymmetrically, for lighting in the up and down directions of a street, by the use of a flat negative electrode. The reason for this is clear, since there is less light obstructed by this electrode in these directions. The greatest advantage of this flat electrode, however, lies in the fact that arcs of lower voltages may be operated; thus 4-ampere arcs can be operated at 65 volts (260 watts) thereby increasing the number of lamps per circuit. Lamps may also be adjusted for as high as 90 volts at the arc (360 watts) resulting in a very high intensity and a somewhat higher efficiency as well. Naturally lamps may also be adjusted for any intermediate voltage. By using lamps adjusted at the higher voltage at central points where a higher intensity of illumination is required, and the lower voltage lamps between, a system of great flexibility

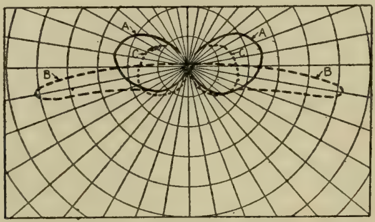


Fig. 4.—Magnetite arc light distribution curves.

may be obtained without any additional apparatus and with only one type of lamp. These adjustments may be made on existing luminous arc lamps. Since it is the current and not the voltage that determines the burning life of the electrode, the trimming schedule will not be affected—and all lamps may be trimmed at the same intervals.

TITANIUM CARBIDE ARC LAMP.

Much developmental work has been done at various times to produce an arc of the magnetite class that will operate on an alternating current circuit. Such an arc, using one electrode composed largely of titanium carbide and the other of carbon, has been developed and is generally known as the titanium or titanium carbide arc. This arc operates on an alternating current series circuit and has the additional advantage of being a low wattage unit; that is, it has a high efficiency at a relatively low energy in-

put. Tests on lamps of this type have shown for a unit consuming less than 175 watts an efficiency of 34 lumens per watt. The distribution of light from such an arc is similar to that from the magnetite arc. The operation of this lamp, however, is not perfectly satisfactory and, although a number have been in commercial operation for some time, the lamp is not yet on the market.

The light distribution from these modern arcs is practically the same for each and it naturally follows that the same mechanical methods of redirecting and utilizing the total light flux will be applicable to each.

PRINCIPLES OF STREET LIGHTING.

The arc lamp always has been used and still is used principally for street lighting. A brief discussion of the principles of street lighting therefore, and the results to be aimed at, may not be inappropriate. Obviously, illumination on the streets is provided so that both pedestrians and vehicles may proceed with ease and safety. In addition to this requirement must be mentioned the protective feature of adequate lighting and the making of streets attractive at night, particularly in the downtown or retail business district.

There are two main types of light distribution advocated. These may be described in terms of the light distribution as directed and diffuse or in terms of the illumination produced as uniform and non-uniform lighting. In the former class, the directed distribution, the aim has been to produce an illumination as uniform as possible by directing a large percentage of the light from the source to the horizontal or a few degrees below. Where the street surface is of dark color and of a highly reflecting nature, such as a well-oiled boulevard, a distribution of this character will produce high specular reflection and excellent vision. In this connection it may be said that some engineers contend that as much light as possible should be redirected to the 80° angle regardless of other considerations; others that the 80° angle is important but also that the light directly underneath the lamp is necessary as well and therefore should remain unchanged; and others that 60° to 70° is the correct angle, since glare is claimed to be annoying when light is emitted between the angles of 65° to 90°.

In the second case, the diffuse distribution producing a less uniform distribution, the object has been to obtain a relatively high intensity near the lamps, neglecting to some extent the lighting at a greater distance. Where the road surface is not such as to provide specular reflection, this method appears to effect the best results, particularly in the case of a light or medium colored street.

STREET ARC LIGHTING ACCESSORIES.

With these general principles in mind the different equipments of electric arc lamps have been developed to produce the desired results.

In the ornamental luminous arc lamp which is used in "white way" or intensive lighting, where upward light is an absolute necessity, a greater total light flux has been made available and used than ever before in modern street lighting practise. Where

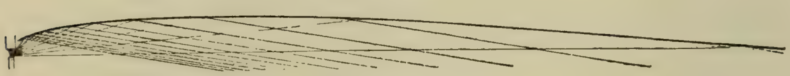


Fig. 5.—Single reflector distribution.

upward light is not necessary, some mechanical means of saving this light must be employed. The simplest theoretical means of redirecting this upward light to the 80° angle would be a single reflector of parabolic shape, its focus being the arc stream (considering it as a point source of light) and its axis coinciding with the 80° light ray. This reflector then, in order to intercept all of the upward light would be approximately 25 ft. (7.62 m.) in diameter and therefore mechanically impossible (Fig. 5).

The next thought that suggests itself is the use of two reflectors, so arranged that all the available light is redirected as in the preceding case. By this arrangement, the external diameter would be reduced to 51 in. (1.29 m.) which would still be too large and unwieldy (Fig. 6). By the addition of a third reflector a still greater reduction in diameter is obtained, the result being a triplane combination of only 26 in. (0.66 m.) in diameter (Fig. 6).

The latest development has been the adaptation of a prismatic refractor only 11 in. (27.94 cm.) in diameter (Fig. 6) in place of a metal reflector. There are two types of prismatic refractors—the band refractor and the totally enclosing refractor. The band prismatic refractor consists of two truncated

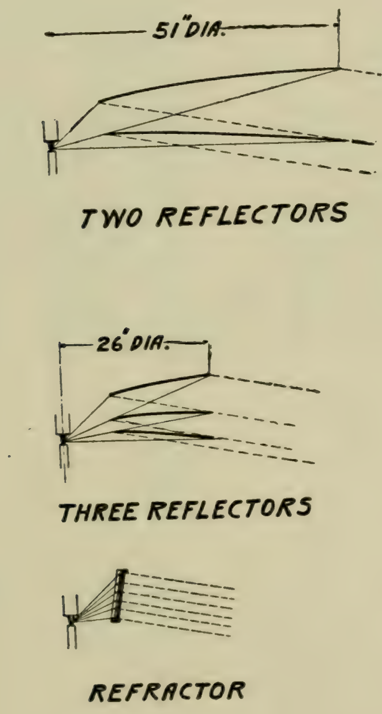


Fig. 6.

conical glass globes or rings, open at the top and bottom, fitting inside one another and forming a single unit which is smooth on both inside and outside surfaces. The inner section is girdled by a succession of horizontal prisms which intercept all the available light rays given off from the light source above the horizontal and deflect them downward at an angle of 10° below the horizontal (as shown in the vertical section, Fig. 7). The

inner surface of the outer section is lined with a series of vertical prisms which serve to diffuse the light (as shown in the horizontal section, Fig. 7). By the use of this type of refractor, the 80° light ray is increased about 100 per cent., the light underneath the lamp remaining the same as from the bare light source (Fig. 4, curve B).

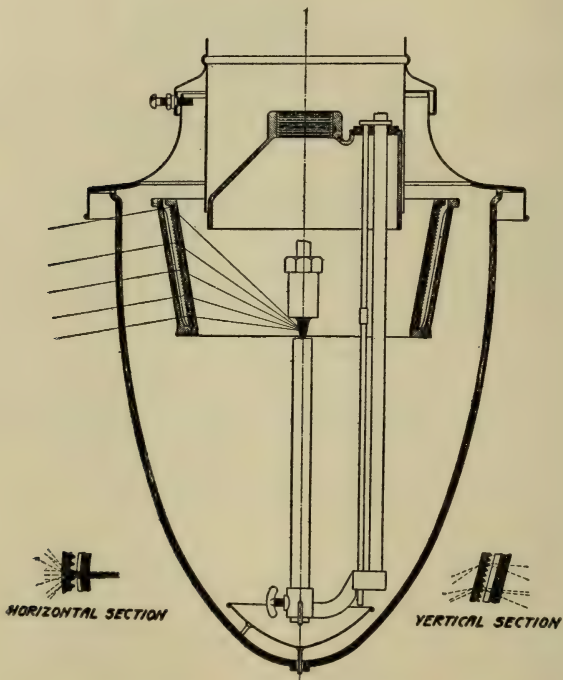


Fig. 7.—Magnetite arc lamp with prismatic refractor.

In the whole refractor, however, the prismatic system is extended down so as to enclose the entire light source, or, in other words, so that all available light rays are redirected at the 80° angle. In the practical application of this prismatic refractor the light is not all redirected and there is of course a small quantity of light diffused at other angles due to imperfections in the glass, etc.

Fig. 3.—Normal 4-ampere luminous arc with bead on positive electrode.

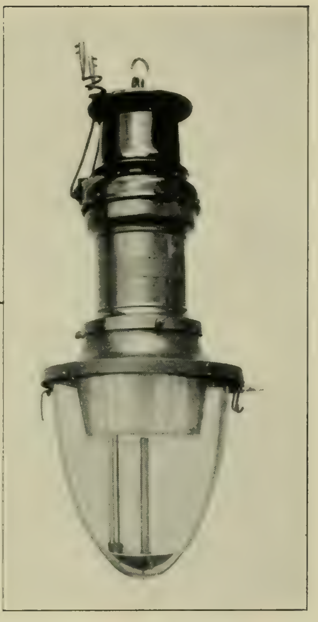


Fig. 8.—Direct current series, 4-ampere, luminous arc lamp with refractor.

Fig. 9.—Ornamental luminous arc lamp mounted on ornamental bracket.

Fig. 10.—Ornamental luminous arc lamp and standard, Washington, D. C.

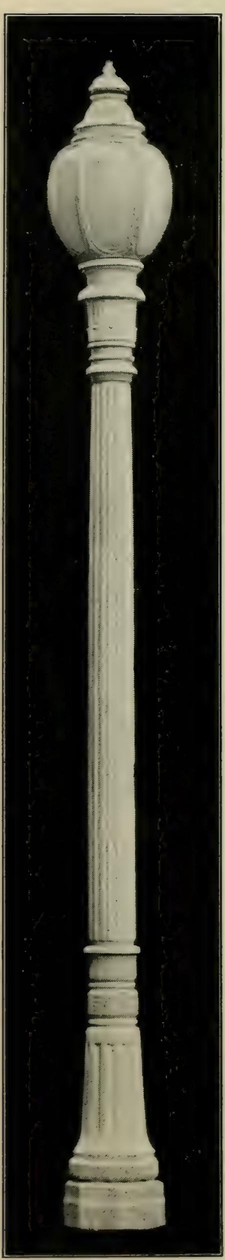


Fig. 11.—Ornamental luminous arc lamp with new panel type globe.

Fig. 12.—Nahant Road, Nahant, Mass., illuminated by luminous arc lamps equipped with prismatic refractors. Height 25 ft., spacing 600 ft.

Fig. 13.—Lynn, Mass., street illuminated by ornamental luminous arc lamps.

Fig. 14.—Lynn Shore Drive, 4-ampere, direct-current, series ornamental luminous arc lamps.

Fig. 16.—Merrimac Street, Lowell, Mass., 6.6-amperes, direct-current, series, ornamental luminous arc lamps.

Fig. 15.—Washington Street, Lynn, Mass., 4-ampere, direct-current, series, luminous arc lamps with light diffusing globes.

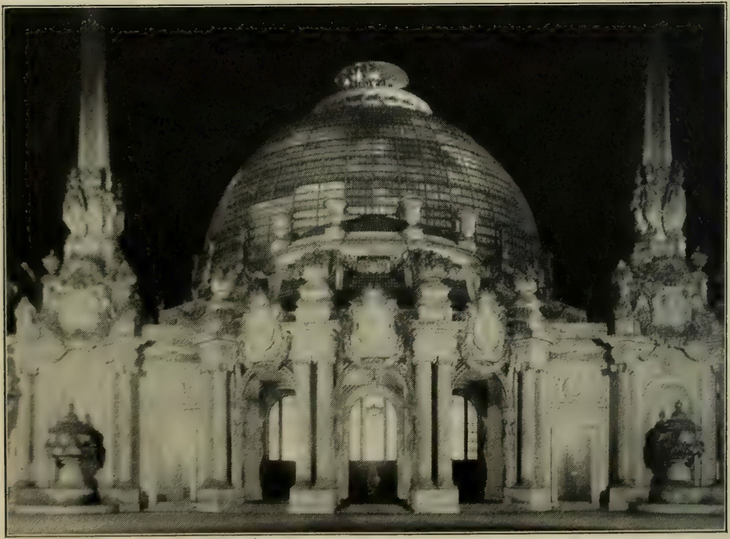


Fig. 17.—East entrance to Horticulture Building, Panama-Pacific International Exposition showing exterior illuminated by ornamental luminous arc lamps.

PENDENT LUMINOUS ARC LAMP.

At the present time there are two distinct types of luminous arc lamps: pendent and upright; the latter are mounted on ornamental standards and brackets. There are about 250,000 luminous arc lamps in operation on 4 to 6.6-ampere direct current series circuits. The latest design of the pendent luminous arc lamp (Fig. 8) has combined the advantages of the former types of luminous arc lamps and has many other improvements as well, different windings being the only difference for the several currents. This latter improvement enables central stations serving several circuits with different currents to carry the same parts for all lamps, with the exception of the windings, and to standardize on a design of lamp which is only slightly different externally from the former types. One of the many improvements in this lamp has been in the design of the upper electrode and its holder. A bar of hard drawn copper enclosed in a steel or brass sheath forms the upper electrode and it can be readily removed from the holder and replaced by another when consumed. The holder is very simple and produces a wiping contact whenever the lamp feeds, thus insuring starting under all conditions.

ORNAMENTAL LUMINOUS ARC LAMP.

The ornamental luminous arc lamps are made for the same current range as noted above. In this type of lamp the operating mechanism has been placed beneath the arc instead of above it. Nearly all the mechanical and electrical parts are interchangeable in the pendent type, which in itself is a great advantage; and both types of lamps may be operated at the same time on the same circuits. The distribution of light is shown in Fig. 4, curve C.

The diffusing glassware of the ornamental luminous arc lamp is dignified and artistic. At the present time there are three distinct shapes: the well known standard with slightly concave sides (Fig. 9); and the Washington type globe (Fig. 10) consisting of twelve segments of diffusing glass held in two metal ribbed hemispherical frames.

The newer lantern or panel type globe (Fig. 11) consists of six or more oval shaped diffusing glass panels contained in a unique fixture of esthetic design. This type of globe is considered by many of those qualified to judge as the most artistic

design for street lighting. One great advantage of the latter two types of globe is that different densities of glass may be used in the separate panels or segments, as desired, so that a dense glass may be placed toward the sidewalk and residences and a light glass on the side toward the street. These lamps at night radiate a powerful and distinctive, pearl white light which is unexcelled and unapproached by any other illuminant on the market.

STREET LIGHTING PRACTISE.

Streets in every city may be classified as follows in order of increasing importance: 1. interurban highways; 2. residential streets; 3. boulevards and parks; 4. secondary business streets; 5. main business street.

Interurban Highway Lighting.—For the lighting of interurban highways where many miles of streets are to be considered and the expenditure of money per mile is necessarily low, the lamps must be spaced at considerable distances apart. Where the surface of the roadway affords a high degree of specular reflection, such as an oiled road, a sufficient intensity near the lamp is required for a reasonably uniform illumination and also a strong beam out at approximately 80° from the vertical. Here the upward light is not of value and all possible use must be made of the specular reflection from the road surface. For such cases the pendent luminous arc lamp with a clear globe and band refractor (Fig. 8) gives excellent results. The arc itself gives a sufficient intensity near the lamp and the refractor redirects the upward light to the 80° angle. These lamps should be suspended at a height of at least 25 ft. to obtain the best results (Fig. 12).

In cases where the street surface is rough or such that no advantage can be taken of specular reflection, a high intensity at or near the 80° angle is of less value and the pendent arc lamp suspended not too high, and equipped with a diffusing globe and perhaps in addition an external reflector to utilize the upward light, is a most satisfactory arrangement.

Residential Streets.—When considering these streets the conditions are somewhat different. Here the lamps must frequently be placed low on account of foliage. The intrinsic brilliancy must therefore not be too high and at the same time there must be

sufficient illumination both on street and sidewalk to make traveling safe. Then, too, some attention must be given to the design of the unit so that at all times it shall make a pleasing and harmonious appearance. For this work the ornamental luminous ing safe. Then, too, some attention must be given to the design of lantern or panel type equipment (Fig. 11) fulfils all requirements. It gives a soft well diffused radiance without glare and of a characteristic white color that enhances vision on street and sidewalk. Also on account of its low intrinsic brilliancy, due to the large size of the globe and the use of glass of suitable density, the light emitted toward the houses is softened and the entire street made more attractive (Fig. 13).

Boulevard or Park Lighting.—Roads of this class are used by automobilists and pedestrians; hence the lighting should be suitable and adequate for each. These roads are frequently arranged with residences on one side and a promenade on the other. In such cases the lighting can best be accomplished by placing the lamps on the promenade side of the street only. Where there are two driveways with a reservation between, the best result may be attained by staggering the lamps on the edge of the reservation, treating each drive separately where the reservation is wide or by placing them in the center of the reservation where it is narrow.

The arc lamps best suited for this lighting are the ornamental luminous arc lamps mounted on 18-ft. standards or the pendent luminous arc lamps equipped with a diffusing globe and external reflector and suspended from 20 to 25 ft. above the ground. When these lamps are used, with a spacing of 250 to 500 ft. (152.40 m.) depending largely on the character of the street surface, an intensity of illumination ample for all purposes is obtained. The use of the ornamental luminous arc lamp enhances the natural scenic attractions at night and the dignified appearance of the unit as a whole harmonizes well with its surroundings.

Secondary Business Streets.—Secondary business streets are those that are mainly side streets, frequently lined with factories, warehouses, etc., streets which are not traversed by pedestrians at night to any great extent. The lighting of such streets as these therefore is primarily for police protection and the pendent luminous arc lamp with diffusing globe, with or without

a reflector, and suspended at a height of 25 ft. (7.62 m.) is the best unit for this purpose (Fig. 15). Also on these streets where there is practically no automobile traffic, these lamps can be adjusted for a minimum voltage and still furnish ample illumination.

Main Business Streets.—The main business streets of the city, namely, those whose stores are essentially retail and depend largely upon show windows for the display of their goods, merchandise or wares, must be lighted to satisfy all, the police, the motorist, the pedestrian or customer and the merchant, and also to bring out in relief the cornices, façades and other architectural effects, thereby creating a favorable impression upon visitors from other cities. This type of lighting is generally known as intensive or "white way" lighting (Fig. 16).

In order to achieve the desired result of fairly intense and uniform lighting, lamps of high candlepower must be employed, at intervals averaging about 100 ft. (30.5 m.), on each side of the street. The ornamental luminous arc lamp is particularly well suited for this class of lighting. Due to the high efficiency of the arc, a sufficient intensity of illumination on the street surface is obtained and makes possible the utilization of upward light. The upward light in the angles adjacent to the horizontal is of utmost importance in the illumination of buildings on both sides of the street. Were this upward light to be wholly suppressed, a dismal and depressing effect would be produced upon the passer-by as a result of the unfinished effect caused by the sharp line of demarcation where the light leaves off and the dark shadow begins. This would be especially true were the light sources of this description themselves screened from view.

This class of lighting is not a fad, for it is well known and highly advertised that trade increases with and follows intensive lighting. In other words, merchants must have good show window lighting in order to obtain trade and attract the attention of prospective customers. The best display of goods will be of little value if people are not attracted to the street by the illumination.

If a bright light is placed outside a show window, the display

inside is made most effective when the light is of a different color, thus producing a contrast with the interior lighting. Where this contrast is present, the show window is attractive and distinctive, and directs attention to the display within. This condition can now be accomplished by the use of the ornamental luminous arc lamp whose pearl white light affords a sharp contrast with the soft lighting of the show windows.

Panama-Pacific International Exposition Lighting.—The ornamental luminous arc lamp is used extensively for the spectacular flood lighting of the beautiful buildings of the Panama-Pacific International Exposition at San Francisco, Cal. (Fig. 17). Exhaustive tests were made with all types of illuminants to determine the proper units for this lighting. The distinctive, white color and the high efficiency of the luminous arc, giving life and contrast to the colored buildings while at the same time bringing out details of carving, veining of marble, etc., in a wonderful manner, showed such excellent effects that it was finally selected. A full description of this lighting may be found in the *General Electric Review.*[1]

Appendices.—Some typical luminous arc lamp installations of the classes of lighting cited above are shown in Appendix A. Appendix B contains a table of adjustments, wattage, candlepower, efficiencies, etc., of arc lamps ordinarily met with in street lighting practise.

[1] Ryan, W. D'A., "Illumination of the Panama Pacific International Exposition," June 1915, p. 579.

APPENDIX A.

Street Lighting Practise with Direct Current Series Luminous Arc Lamps.

Class of street	City and street	Description of street	Width in feet	Height in feet	Spacing in feet	Location	Amps.	Terminal watts	Mounting	Accessories
Interurban Highways.	Nahant, Mass. Nahant Road.	Tar surface macadam —level and straight.	36	25	600	One side	4	310	Pendent	Clear globes, band prismatic refractors, high efficiency electrodes.
	Swampscott, Mass. Paradise Road.	Oil surface, crushed stone—hilly and bad curves.	28	25	500-600	One side	4	310	Pendent	Clear globes, band prismatic refractors, high efficiency electrodes.
	Marblehead, Mass. Salem Street.	Tar surface, crushed stone and fine gravel —level and straight, one long hill, sharp curves.	37	23	750	One side	4	310	Pendent	Clear globes, band prismatic refractors, high efficiency electrodes.
Residential Streets.	Lynn, Mass. Nahant Street.	Tar surface macadam —straight and hilly.	47	14.5	500	Staggered	4	310	Ornamental poles	Washington type ornamental globes, high efficiency electrodes.
	Swampscott, Mass. Humphrey St.	Wood paving blocks— —level and curved.	52	18	700	Staggered	4	310	Ornamental poles	Washington type ornamental globes, high efficiency electrodes.
Boulevards.	Lynn, Mass. Lynn Shore Drive.	Tar surface macadam —level and curved.	40	18	250-300	One side	4	310	Ornamental poles	Ornamental globes, high efficiency electrodes.
	Boston, Mass. Commonwealth Avenue.	Tar surface. Two drives 35 ft. wide each and 100-ft. wide park between.	170	22-28	325	Lamps on park side of drives— staggered.	6.6	510	Pendent	Diffusing globes and external reflectors, long-life electrodes.
	Boston, Mass. Huntington Avenue.	Asphalt drives. 26 ft. wide each, straight, 26-ft. electric car reservation between.	78	18	150	Lamps on residential side of drives —staggered.	6.6	528	Ornamental poles	Ornamental globes, long-life electrodes.

APPENDIX A.—(*Continued.*)

Class of street	City and street	Description of street	Width in feet	Height in feet	Spacing in feet	Location	Amps.	Terminal watts	Mounting	Accessories
Secondary Business Streets.	Lynn, Mass. Broad Street.	Granite paving stones—level and straight.	43	18	500	Staggered	4	310	Ornamental poles	Ornamental globes, high efficiency electrodes.
	Lynn, Mass. Washington St.	Granite paving stones—level and straight.	34	25	800	Staggered	4	310	Pendent	Diffusing globes and internal reflectors, long-life electrodes.
Main Business Streets.	Lynn, Mass. Market Street.	Bitchulumn pavement—level and straight.	50-70	14.5	80-100	Staggered	6.6	528	Ornamental poles	Ornamental globes, long-life electrodes.
	Andrew Street.	Bitchulumn pavement—level and straight.	34	14.5	120	Staggered	6.6	528	Ornamental poles	Ornamental globes, long-life electrodes.
	Munroe Street.	Granite paving stones—level and straight.	32	14.5	120	Staggered	6.6	528	Ornamental poles	Ornamental globes, long-life electrodes.
	Oxford Street.	Hassam pavement—level and straight.	36	14.5	110	Staggered	6.6	528	Ornamental poles	Ornamental globes, long-life electrodes.
	Beverly, Mass. Cabot Street.	Cement surface, granite paving stones—level and straight.	35	14.5	140	Staggered	5	400	Ornamental poles	Ornamental globes, high efficiency electrodes.
	Melrose, Mass. Main Street.	Cement surface, granite paving stones—level and straight.	42	14.5	160	Staggered	5	400	Ornamental poles	Ornamental globes, long-life electrodes.
	Washington, D. C. Pennsylvania Avenue.	Asphalt—level and straight.	109	15	100	Staggered	6.6	528	Ornamental poles	Washington type ornamental globes, long-life electrodes.

APPENDIX B.—ADJUSTMENTS, MEAN SPHERICAL CP., & EFFICIENCIES OF SERIES ARC LAMPS.

Type of lamp							Unequipped lamp			Equipped lamp					
										Clear globe			Prismatic refractor		
	Circuit	Amp.	Terminal volts	Terminal watts	Electrode or carbon	Life in hours	Scp.	Watts per scp.	Lum'ns per watt	Scp.	Watts per scp.	Lum'ns per watt	Scp.	Watts per scp.	Lum'ns per watt
Open carbon	D. C.	9.6	50	480	—	12-15	—	—	—	450	1.07	11.8	—	—	—
Enclosed carbon	A. C.	6.6	77	430	—	100	—	—	—	140	3.06	4.1	—	—	—
"	A. C.	7.5	77	480	—	90	—	—	—	173	2.72	4.6	—	—	—
"	D. C.	6.6	73	480	—	100	—	—	—	281	1.71	7.3	—	—	—
Open flame carbon . . .	D. C.	6.6	75-80	510	White	15-18	—	—	—	1,243	0.41	30.6	—	—	—
"	D. C.	6.6	75-80	510	Yellow	15-18	—	—	—	2,048	0.25	50.4	—	—	—
Enclosed flame carbon . .	A. C.	10.0	60	465	White	100	1,487	0.31	40.2	889	0.52	24.0	—	—	—
"	A. C.	10.0	60	465	Yellow	100	1,690	0.27	45.6	1,013	0.46	27.4	—	—	—
"	D. C.	9.6	50	480	White	100	2,300	0.23	60.1	1,091	0.44	28.5	—	—	—
"	D. C.	9.6	50	480	Yellow	100	2,650	0.20	69.4	1,297	0.37	34.0	—	—	—
Luminous	D. C.	4.0	75-80	310	Long life	350	313	0.99	12.7	264	1.17	10.7	259	1.20	10.5
"	D. C.	4.0	75-80	310	High eff.	180	560	0.55	22.8	424	0.73	17.2	400	0.78	16.2
"	D. C.	5.0	75-80	388	Long life	225	463	0.84	15.0	426	0.91	13.8	412	0.94	13.3
"	D. C.	5.0	75-80	388	High eff.	150	872	0.44	28.3	610	0.64	19.7	578	0.67	18.7
"	D. C.	6.6	75-80	510	Long life	110	1,052	0.48	25.9	741	0.69	18.3	714	0.71	17.6
"	D. C.	6.6	75-80	510	High eff.	110	1,565	0.32	38.5	995	0.51	24.5	940	0.54	23.1

NEW TYPES OF INCANDESCENT LAMPS AND THEIR RELATION TO THE STREET LIGHTING PROBLEM.*

BY W. H. ROLINSON.

Synopsis: The following paper is intended to present such data as are now available on the application of the mazda "C" lamp to street lighting. Attention is called to the fact that although this lamp is a newcomer in this field it has already proved itself of great value due to the wide range of types and sizes available and to the great variety of accessories which have been developed with street lighting requirements in view. Data are given on the life performance of the types of lamps most frequently employed, and also on the light distribution of the accessories with which they are used. The question of proper accessories for use with this type of illuminant is discussed and photographs of typical installations which have proved satisfactory are shown. The most commonly employed types of circuits are described and data are presented on the operating characteristics of the following alternating current series circuits: (1) constant current (moving coil) regulators with film cut-out sockets; (2) adjustor socket systems; (3) series reactance coil regulators or phase displacement transformers with film cut-out sockets; (4) series film cut-out socket directly connected in series across constant voltage circuits.

INTRODUCTION.

The purpose of this paper is to outline the progress of street lighting by mazda[1] type "C" lamps, as represented by present installations, to bring together data regarding distribution systems, and such equipment and data as is available at this time. These lamps have been on the market not over a year and a half, yet this seems to have been long enough to establish confidence in them, especially in the types that are used in street lighting. At present there are almost half a million of these lamps installed and operated successfully in streets in the United States and the number is being increased rapidly.

The many and varied conditions encountered in street lighting have long required units of a wide range in candlepower for street service. It is therefore not surprising that the development of the lamps, and the design of fixtures and other controlling accessories for their proper application, has progressed rapidly. It is now possible, at a comparatively low cost and at excellent efficiency, to provide street illumination of any intensity with this form of illuminant.

* A paper presented at the ninth annual convention of the Illuminating Engineering Society, Washington, D. C., September 20-23, 1915.

[1] Wherever tungsten lamps are mentioned or illustrated in this paper only mazda lamps are referred to.

REQUISITES OF STREET LIGHTING.

In the brief period since these lamps have made their appearance they have been developed so that they cover and are suited to practically all conditions of street lighting. The requisites of street lighting as reported by the Street Lighting Committee of the National Electric Light Association in 1914 are as follows:

1st. Discernment of large objects in the street and on the sidewalk.
2nd. Discernment of surface irregularities in the street and on the sidewalk.
3rd. Good general appearance of the lighted street.

These objects can be served in two general ways, namely, close spacing of light sources, producing fairly uniform light intensities, and wide spacing of units, producing non-uniform light intensities.

Without recommending the uniform or non-uniform street lighting as the better system, it can be said that the lamps adapt themselves to either, depending upon the method of installation and the accessories used.

SYSTEMS GENERALLY USED.

Street lighting on multiple circuits is not common in the United States although it is extensively used in New York City and with such systems very satisfactory results are being secured. The series system is generally installed in one of the following ways:

1. Constant current (moving coil) regulators with film cutout sockets. 2. Adjustor socket systems. 3. Series reactance coil regulators or phase displacement transformers with film cutout sockets. 4. Series film cutout sockets directly connected in series across constant voltage circuits.

DIRECT CURRENT SERIES CIRCUITS.

As far as is known the life performance of type "C" series tungsten lamps on direct current circuits is the equivalent of their performance on alternating current circuits although some peculiar characteristics have been noted on such circuits, particularly in conjunction with certain kinds of arc lamps which tend to set up excessive line surges. After some study and investigation it is now possible to operate the lamps with satisfactory results on these circuits if the character of the circuit employed is

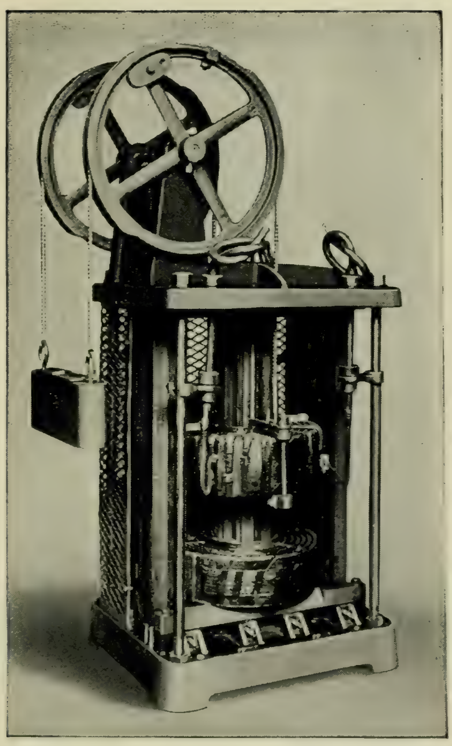


Fig. 1.—Constant current regulator (ventilated coil).

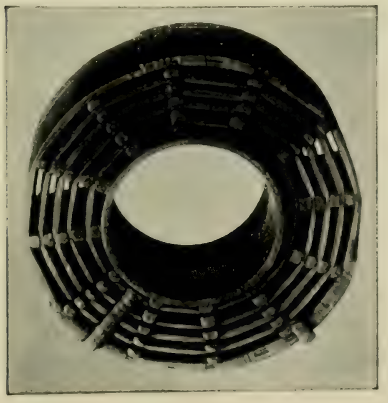


Fig. 2.—Coil for constant current regulator.

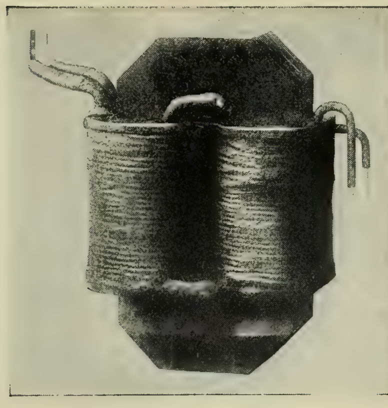


Fig. 10.—Autotransformer.

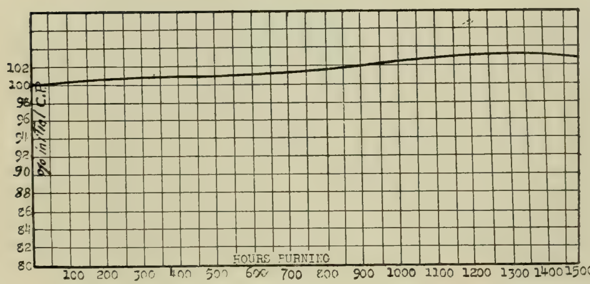


Fig. 11.—Curve showing cp. life performance of five 80-cp. 6.6-amp. type "C" tungsten lamps.

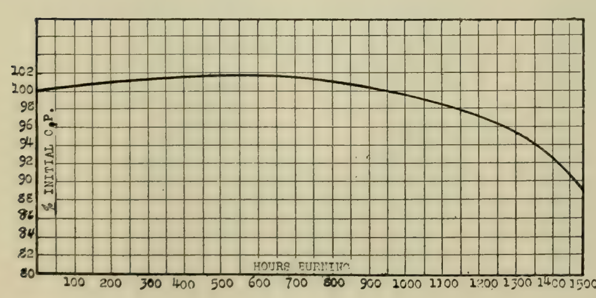


Fig. 12.—Curve showing cp. life performance of five 600-cp. 20-amp. type "C" tungsten lamps.

definitely specified at the time the lamps are secured from the manufacturers.

On direct current circuits it was found that occasionally when lamps burned out the arc would continue across the ruptured filament sometimes to the extent of destroying the socket before it had been extinguished. By means of a cutout device, now the basis of experiment, it is expected that lamps of this type can be made to operate as satisfactorily on these circuits as on the more usual alternating current circuits and that the occasional annoyance of sockets being destroyed will be eliminated.

It must be said in passing that as yet these lamps cannot be generally recommended for operation on any form of direct current series circuit. However, such little difficulties as have appeared in the past are rapidly being overcome so that within a very short time many of the disadvantages of such operation are expected to be eliminated.

ALTERNATING CURRENT SYSTEMS.

The constant current regulator system is one of the most satisfactory systems of operating gas-filled tungsten lamps for street lighting. The most common form consists of a primary and secondary coil surrounding a common core, one of which coils is movable and balanced by a counter weight, as shown in Fig. 1.

This constant current regulator is typical of the various kinds now in use. The latest designs have coils constructed so that every part can be readily cooled by the surrounding air, there being no part of any coil more than ½ inch (12.7 mm.) thick, as illustrated in Fig. 2.

The principal advantage of this form of distribution system is, that with grounds and short circuits on the secondary the moving coil changes its position to maintain normal current regardless of their severity, doing so within three seconds.

Fig. 4 shows curves which indicate the regulation characteristics of a constant regulator with various operating conditions and in comparison with other systems.

The film cutout socket for such a system is comparatively well known and consists essentially of the two brass jaws of the socket held apart by a thin piece of insulation. The failure of the lamp causes the full voltage of the open circuit to be impressed against

this insulation, which punctures and allows the circuit to remain uninterrupted.

The adjustor socket system differs from other methods in that a different type of lamp cutout is employed; it consists of a multiple socket which is shunted by a reactance coil permanently connected in circuit. This reactance coil is designed so that when a lamp is in circuit the coil takes only an exciting current which approximates 2 per cent. of the line current. When the

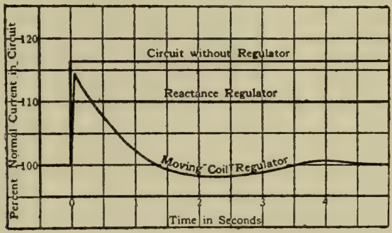


Fig. 4.

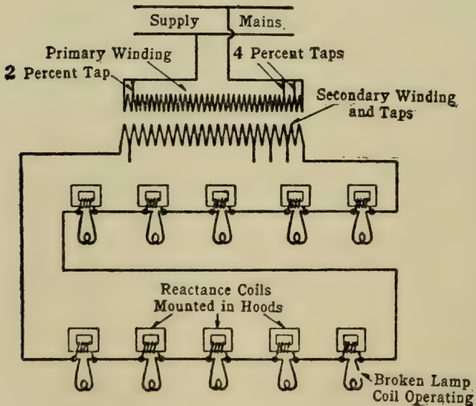


Fig. 6.

lamp fails or is removed all the current is forced through the coil, which introduces a high reactance in series with the other lamps, and thus prevents the current from rising unduly although operated on a constant potential circuit. The system is operated in connection with a constant potential transformer which is provided with suitable voltage taps to enable the adjustment of the circuit voltage to within 1 per cent. that required. Fig. 6 shows a characteristic diagram of this circuit.

The series reactance coil regulator is a device consisting of a constant potential transformer with an adjustable reactance in series with a circuit of lamps, cutting down the power factor to

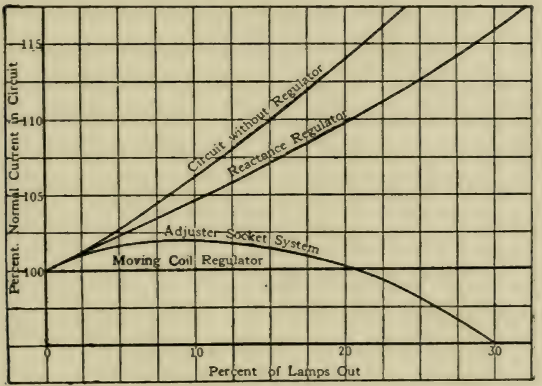


Fig. 7.

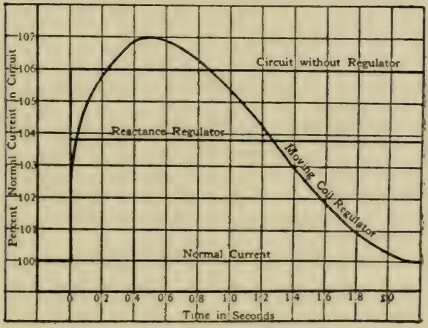


Fig. 8.

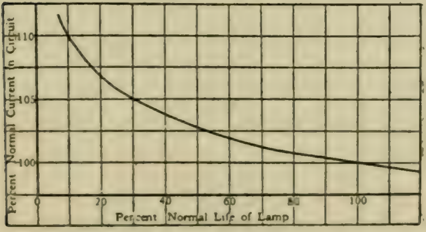


Fig. 9.—Life curves of gas-filled tungsten lamps with various currents.

approximately 80 per cent. and thereby reducing the rise in current from any cause. With any change from normal conditions, such as lamp outage, double grounds and short circuits on the

lamp circuit, the current rises approximately 70 per cent. as much as it would if no reactance regulator were used. This system is used very rarely and it cannot be recommended as a satisfactory system, except for temporary use.

The series film cutout system, using lamps connected directly in series across constant voltage circuits with film cutout sockets, is primarily an emergency system. It is too unreliable to warrant risking lamps in any considerable number because of the chance of a few lamps burning out and perhaps destroying those remaining.

In Figs. 7 and 8 are shown the regulation characteristics of the various circuits briefly outlined above, with various percentages of lamps inoperative and with a 10 per cent. rise of the primary voltage. A study of these curves will indicate the superiority of the constant current transformer system from the standpoint of its reliability and protective features to the lamps on the system.

CURRENT SURGES.

Although the lamps in themselves contain a sufficient factor of safety for satisfactory operation on the more commonly employed forms of series lighting circuits, the matter of regulation on such circuits should be given considerable attention. In Fig. 9 the performance of mazda lamps is shown to indicate the effect of continuously applied variations of current on the lamp performance by improper operation.

On lamps of the larger sizes it is recommended that from the standpoint of efficiency, as well as the factor of safety introduced, that the 15 and 20-ampere lamps be operated in conjunction with autotransformers. At average prices of power, the autotransformer or compensator pays for itself within a few months in the wattage saved over the less efficient lower current lamps, and in itself provides additional protection to the lamp.

AUTOTRANSFORMERS.

The autotransformer eliminates the necessity for a film cutout socket inasmuch as the open circuit voltage of the secondary of the autotransformer amounts to only two or three times the lamp voltage and the autotransformer is not injured by continuous operation on open circuit.

As a general feature it may be stated that a 100 per cent. over-current on the primary increases the current on the secondary or across the lamp terminals something less than 50 per cent., so that, except under the most abnormal conditions, the lamps are protected from destruction by any ordinary electrical disturbance. With lamps operated at a temperature relatively close to the filament melting point, this may in certain installations be an extremely valuable feature.

When autotransformers, larger than the 60-cycle, 1,000-candle-power, 6.6-ampere to 20-ampere rating, are desired, for instance those for 25-cycle service, the autotransformer is mounted in a different position and made of a slightly different shape, the only change in the fixture case being that the central portion of the copper section is slightly lengthened to take care of this longer autotransformer.

The autotransformer used with the mazda type "C" lamps is essentially a current transformer. A single winding is used for the sake of economy as there would be no advantage in making two windings insulated from each other and requiring considerably more material to obtain the same results. With the present autotransformers a core type construction is used: first, for ease of permanent insulation; second, for high efficiency and power factor because of size and compactness, and third, uniformity of performance with reference to leakage and compensation. The autotransformer itself costs approximately the same as the lamp which is used with it.

PERFORMANCE OF SOME STANDARD SIZES OF AUTOTRANSFORMERS, 6.6 AND 7.5-AMPERE PRIMARY AT 60 CYCLES.

Cp.	Lamp current	Efficiency	Watts	Power factor
400	15	94.5	200	98
600	20	95.2	282	98
1000	20	95.8	450	98

ADAPTABILITY OF LAMPS.

The gas-filled tungsten lamp, as illustrated by the various circuits on which it can be employed, is adaptable to practically all forms of street lighting and distribution systems. The method of manufacture of the lamp is such that the depreciation of candle-power throughout life is at a minimum and in fact in some of the

smaller lamps the candlepower throughout life is in excess of its initial value. In Figs. 11 and 12 the life performance of the 80-candlepower, 6.6-ampere lamp and the 600-candlepower, 20-ampere lamp is illustrated as being typical of the candlepower performance of the series type "C" lamps in general.

FIXTURE REQUIREMENTS.

The large, high candlepower lamps on account of their characteristics and extreme brilliancy require that they be used in connection with proper fixtures suitably adapted to the lamp and the conditions of service. The life of the lamp and the efficiency of the complete unit are vitally affected by the kind of globe and the ventilating facilities of the fixture.

To get a reliable and adequate service from these high candlepower gas-filled tungsten lamps the fixtures must be designed in such a way as to give not only adequate ventilation but at the same time provide complete protection from the elements; for when the lamp is in operation, the bulb is extremely hot and will crack on exposure to rain or snow.

The smaller street series lamps of 250 candlepower or less can be operated in the ordinary forms of street hoods without any additional protection from the weather. The ordinary street hoods protect the upper parts of the lamp sufficiently and the lower portions of the lamp, being comparatively cool, are not affected.

The position in which a gas-filled tungsten series lamp is burned very often materially affects the life of the lamp. The regularly manufactured series lamps are designed to operate in a pendent position, tip-down, but very often the fixture to which the lamp must be adapted requires that it be operated in a tip-up position. In such cases special construction is necessary in order that a satisfactory life be obtained from the lamps. Care should always be taken to specify the position of burning in order that the right lamp will be secured.

In Fig. 13, *a, b, c, d, e,* and *f* shows the kind of fixtures generally used with these lamps. These fixtures are fitted either with an autotransformer for operating more efficient high current lamps or with film cutout sockets for operation on the standard circuits of 6.6 and 7.5 ampere values.

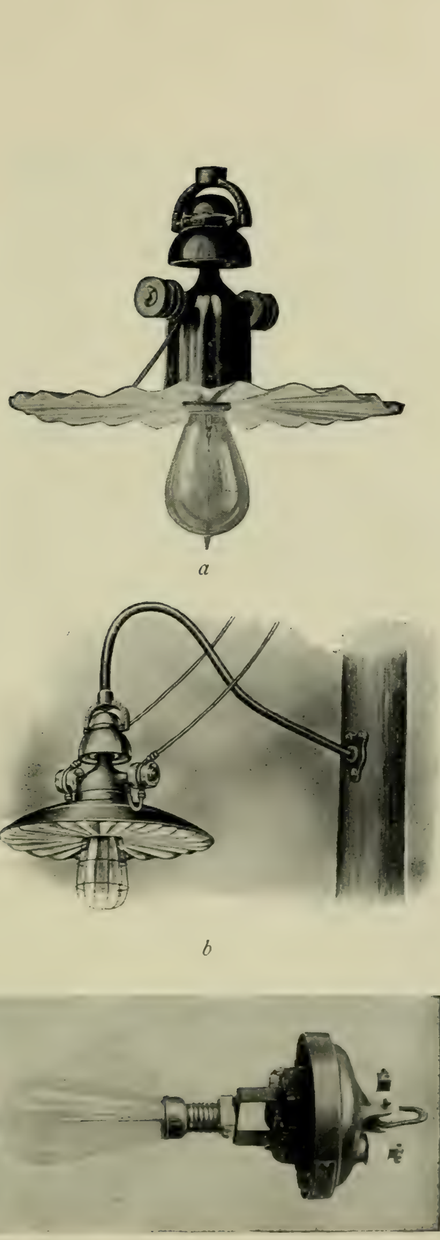
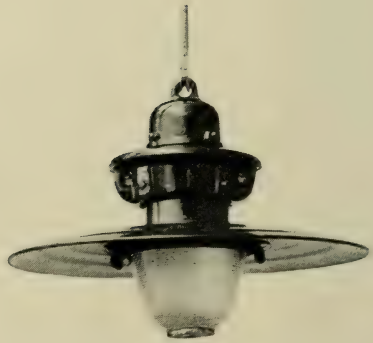


Fig. 13.—Type "C" fixtures.

d

e



f

Fig. 13.—Type "C" fixtures.

The exclusion of insects is also an important requirement for street lighting fixtures. As these fixtures are hung in comparatively inaccessible places the frequency of visits necessary to remove insects should be reduced as much as possible; this can be taken care of by selecting only fixtures of proper construction and design.

The appearance of a street lighting unit is always of importance inasmuch as it occupies the most conspicuous position of any piece of electrical apparatus. Fixtures of symmetrical appearance when used with or without reflectors are very desirable.

There are a great many fixtures on the market suitable for operating these lamps. Most of these are so standardized that they can be used interchangeably on various circuits and are also standardized so as to adapt a variety of diffusing globes and refractors.

GLASSWARE.

A globe for diffusing the light from the concentrated tungsten filament gas-filled lamp is very desirable, especially where it is mounted in such a way as to fall within the line of vision.

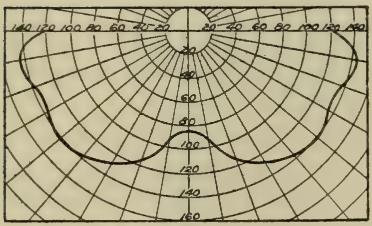
While diffusing glass is recommended and has many advantages it has also the disadvantage of reducing the efficiency of the unit. The ideal globe, of course, is one which is of sufficient diffusing power to entirely conceal the lamp filament and become itself a secondary source of light, thus becoming luminous over its entire surface without the absorption of too great an amount of light flux. The opalescent glass commonly used absorbs from 15 to 30 per cent. of the light.

The globes made of cased glass of two different mixtures are very valuable; such glass is usually of the best diffusing quality and correspondingly ornamental. Although the light absorption is somewhat greater than that of the common opalescent glasses, the absorption is diminished by having the glass relatively thin and part of the thickness of the globe made of clear glass.

A refractor if carefully placed with reference to the light source can be used to redirect the light rays in desirable directions.

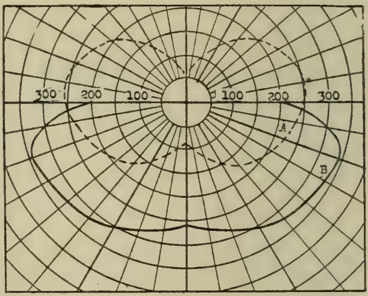
LIGHT DISTRIBUTION CURVES.

It is obvious that the character of light distribution of units for street lighting is a matter of considerable importance and it must be stated that the fixtures illustrated have been designed with this



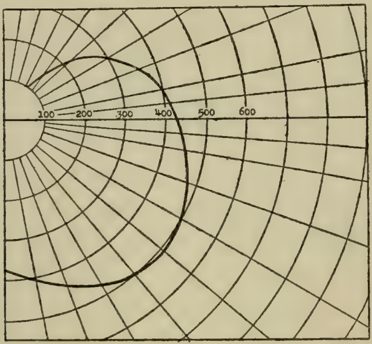
a

100-cp. mazda series lamp with radial wave reflector.



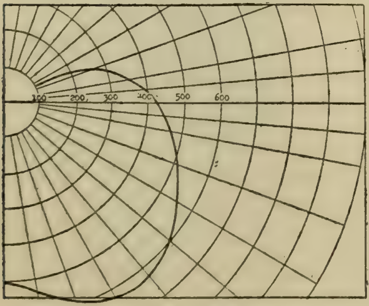
b

250-cp. mazda series lamp with radial wave reflector.



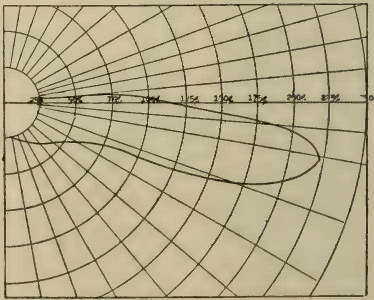
c

600-cp. mazda series lamp with Alba glass globe and no reflector.



d

600-cp. mazda series lamp with Alba glass globe and enameled reflector.



e

600-cp. mazda series lamp with enameled reflector and prismatic reflector.

Fig. 14. Light distribution characteristics of several fixtures.

requirement in mind. In Fig. 14, *a, b, c, d,* and *e* are shown the distribution characteristics of some of the more typical forms of fixtures now installed.

CITY LIGHTING.

Lamps of the larger sizes have been used quite successfully in many of the larger cities of the country. In the majority of instances no attempt has been made to adopt any new method of installation, spacing of units or mounting height; usually the mazda "C" lamps and fixtures that have replaced the various forms of carbon arc lamps have been located on the same poles. In practically every instance where these lamps have replaced arc lamps, incandescent units of greater candlepower were selected, resulting in increased illumination. The accompanying illustrations show several typical city lighting installations. Fig. 15 shows the lighting of upper Broadway, New York City, in which 400 and 500-watt, multiple gas-filled tungsten lamps have been used to replace carbon arc lamps. These lamps were mounted in the same positions that the arcs occupied. Figs. 18, 19 and 20 show installations of 20-amp., 600-cp. gas-filled tungsten lamps.

Fig. 18 is a photograph of Springfield Avenue, Newark, N. J. Fig. 19 is a night view of Ogden Avenue, Chicago, Ill. Fig. 20 shows the lighting on a street in Carlisle, Pa., the lamps being equipped with prismatic refractors mounted from 18 to 22 ft. (5.48 to 6.70 m.) and irregularly spaced on 250 to 500-ft. centers.

ORNAMENTAL SYSTEMS.

The ornamental systems of street lighting, which have proved themselves very popular in many communities, are typically illustrated in Figs. 21, 23, 24 and 26.

The new type of gas-filled tungsten has simplified this system by stimulating the demand for single lamp standards. The five-lamp light clusters, which were installed in such large numbers in the business sections of smaller cities, are now becoming less of a factor, being superseded by the single lamp standards of artistic design. The new mazda lamps of the 400 and 600-candlepower size adapt themselves very readily to the single light standards of the ornamental lighting systems; Figs. 15, 19, 21, 23, and 26.

By means of a two-winding transformer placed in the pole base, using 400-candlepower, 15-ampere or the 600-candlepower,

20-ampere lamps, a very ornamental and efficient form of street lighting can be employed as the use of the two-winding transformer in the pole base provides means of carrying a low tension current up through the pole, making it a very satisfactory street series system.

There are many designs of ornamental pole units; most of those used are of a standard cast-iron construction. It should be noted that concrete poles, suitably designed to harmonize with the surroundings, are being used to some extent. Perhaps the most typical and largest example of ornamental lighting by gas-filled lamps on concrete standards is illustrated in Fig. 21, showing the lighting of Lakeshore Drive, Chicago, Ill.

HIGHWAY LIGHTING.

The subject of lighting of highways, state roads or other long interconnecting roads between communities, which in general remain unlighted, deserves some consideration.

With the steady extension of transmission and distribution systems through the more sparsely settled sections of the country, the chief item of expense, pole line construction, is minimized in many localities. By means of some of the aforementioned distribution systems, lighting along highways of this character can often be carried out on transmission lines in the immediate vicinity. In such places where highway lighting of the kind suggested has been employed it has generally been accomplished by means of the low candlepower lamps fitted either with radial wave reflectors or with lamps and reflectors supplemented by the prismatic refractors. Generally speaking, lighting of this nature can be considered merely to be beacons and no pretense has been made to illuminate the roadway uniformly.

At this writing it seems not feasible to recommend any system to provide adequate highway lighting, as most of the travel along these roads is by means of automobiles or other vehicle and a very low intensity of illumination sufficient only to outline the general direction of the road is necessary. With lighting of this character, vehicles on the road are discernible by means of a silhouette effect which seems to be sufficient.

It has been suggested that in lighting of this character, even though small lamps are used, that the suspension be as near the

Fig. 15.—Upper Broadway, New York City.

Fig. 18.—Springfield Avenue, Newark N. J.

Fig. 19.—Ogden Avenue, Chicago Ill.

Fig. 20.—A street in Carlisle, Pa.

Fig. 21.—Lakeshore Drive, Chicago, Ill.

Fig. 23.—A street in Corning, N Y.

Fig. 24.—Ornamental street lighting standard.

Fig. 26.—Meridan Street, Indianapolis, Ind.

a *b*

Fig. 29.—Ornamental standards.

Fig. 30.—A street in Sellersville, Penna.

Fig. 31.—Jarvis Lane, Sea Girt, Far Rockaway, N.Y.

Fig. 32.—Queensboro Bridge, New York City.

center of the road as possible and not much lower than 18 ft. (5.48 m.) above the street surface. On ordinary dirt roads the 100 candlepower lamps with radial wave reflectors, either with or without a refractor, spaced 200 to 300 ft. (60.96 to 91.44 m.) apart, appear to give very satisfactory lighting. This spacing, of course, would be used only where roads are comparatively straight; where a road changes directions, such as around curves and over bridges, railroad tracks, etc., it is suggested that the spacing be made to conform to the conditions.

On the better class of state roads where road surfaces have been oiled and have become somewhat polished through vehicular traffic, larger units of 250 to 400-candlepower sizes, spaced from 500 to 600 ft. (152 to 182 m.) apart and at heights not less than 20 ft. (6.09 m.) prove a more satisfactory form of illumination. It is, of course, necessary in all cases to have the units located with reference to the natural obstacles.

CONCLUSION.

The writer wishes to draw attention to the new mazda lamp, known in trade as the mazda "C" type, with its accessories, as being a complete system for street illumination in itself. The most out-of-the-way country road or infrequently used city alley may be as appropriately lighted as the most prominent boulevard or business street in the more populous community. The lamps have demonstrated without question their ability to withstand, under usual operating conditions, the difficult service required of them. Their uniformity of performance, high maintenance of candlepower, ease of installation and simplicity of operation have won for them a prominent place in the street lighting field of the country. They are made of sufficient size and in sufficient variety to light an entire community and under proper operating conditions may be used to supplement or to operate directly in conjunction with arc lighting installations.

Appreciation is expressed for the kind assistance of Mr. E. J. Dailey, Jr., in the preparation of this paper, for the helpful suggestions of Mr. H. A. Tinson of the Edison Lamp Works of the General Electric Co. and Mr. W. P. Hurley of the Westinghouse Electric & Mfg. Co.; and also for the courtesy of the Publicity Department of the Westinghouse Electric & Mfg. Co. and the General Electric Co. in furnishing the photographs used herein.

A PRACTICAL APPLICATION OF THE PRINCIPLES OF SCIENTIFIC STREET LIGHTING.*

BY F. A. VAUGHN.

Synopsis: This paper describes the routine steps taken in planning and carrying to completion a street lighting system embodying in practise certain principles of scientific street lighting set forth by the writer's associate in a paper recently read before a section of the I. E. S. The two papers jointly are intended to form a more or less complete treatise on the theory and practise of street lighting as indicated by the principles elucidated in the earlier paper.

INTRODUCTION.

In this paper, an effort has been made to describe and illustrate by a review of an actual plan for a street lighting system, the embodyment of the "Principles of Scientific Street Lighting," as set forth in a paper read by the writer's associate, Mr. A. J. Sweet, before the Chicago Section of our society, May 21, 1915; and to emphasize the fact that, if principles of this sort were more generally recognized and applied by engineers having in charge the planning and installation of street lighting systems, considerable advance would be made in the art of illuminating the streets, thoroughfares and public spaces.

ESTABLISHMENT OF PRINCIPLES.

By an analytical study of the purposes and requirements of street lighting and the establishment of principles which can be followed in practise, the same improvement which has been accomplished in interiors can be realized on the exterior. Exterior illumination has not, however, kept abreast of the advancements in interior illumination. The discrepancy between the two, along with the greatly increased use made of the streets at night, has created, in the minds of a public which has been educated to appreciate the benefits of good and sufficient illumination, an insistent demand for better street lighting, and for more scientifically and appropriately designed systems. The subject

* A paper presented at the ninth annual convention of the Illuminating Engineering Society, Washington, D. C., September 20-23, 1915.

has thus become to-day perhaps the livest one with which the illuminating engineer has to deal; and he must meet it on a sound, scientific, engineering basis, since his own efforts to promulgate the proper use and amount of light in interiors has created a status of mind in the public which can no longer be satisfied on any other basis. One cannot uneducate those who have been educated.

Such analytical studies and investigations, as were referred to above, are now being made by a few men in this country, and the result of their progress is exemplified by the papers of Mr. Sweet, already referred to, and the one recently read by Mr. P. S. Millar before the joint meeting of the I. E. S. and the A. I. E. E. These papers, although not in agreement on all points, indicate the formulation of definite ideas on the subject.

The present paper will, therefore, not dwell upon the establishment of the principles governing well-designed street lighting systems, but upon the carrying out of those principles, particularly those in the former paper, in practise, and the adjustment of them to conditions found in practical installations, leaving those interested to follow up the above references. It was thought that this object would best be attained by describing the actual application of the principles to a specific case, supplementing the discussion by illustrations of their application to a proposed system in a large city in this country.

The balance of this paper, therefore, will be almost entirely excerpted from a report recently submitted to the City of Milwaukee, Wisconsin, with full recommendations for an entire street lighting system. This, it was thought, would form the best basis for a discussion of the subject chosen, as the recommendations were made with a definite purpose of applying† to the problem, as far as feasible, the principles referred to above.

THE PROBLEM.

It will be assumed that the problem comprises a complete street lighting survey of the city and recommendations as to the best manner in which to light its thoroughfares, streets, alleys, parks and other public spaces, and that the problem can be approached from a viewpoint practically free from restrictions and

† Since the presentation of this paper, a portion of this installation has been completed, and views of parts of the actual installation have been incorporated in following pages.

unhampered by traditions or precedents. In other words, the problem has been solved by assuming no restrictions in working out what might be believed to be the best and most advanced methods which the knowledge available to-day and the sound and rational predictions for the future would justify. No extensive comparisons of different available apparatus will be indulged in, as it is believed that the decisions will usually convey the reason for the exclusion or adoption of any specific equipment.

PRACTICAL APPLICATION OF PRINCIPLES TO PROBLEM.

The routine work of applying these principles to the problem is divided into the following general sub-divisions:

Preliminary Considerations.—(*a*) Division of the city into zones or districts, according to their important characteristics which govern the type of street lighting unit to be employed.

(*b*) Study of traffic conditions, forestation, present system of poles and lines, and other exceptional conditions affecting general rules.

(*c*) Determination of proper intensity of illumination for each class of street, and for every district in the city, including alleys and parks.

(*d*) Selection of the type of unit for each zone or district, including lamps, fixtures, posts and equipment.

Engineering Considerations.—(*e*) The adaptation or design of the units as selected under (*d*), including the detailed mechanical and electrical design of novel features if necessary, and the actual development of the equipment, through manufacturing concerns, public utility companies, or others.

(*f*) Establishment of the best theoretical spacing, or distance, between units on all streets and their mounting heights, taking into consideration (*a*), (*b*), (*c*), and the recording of these data on large scaled maps of the city made for this purpose.

(*g*) Checking and adjusting the above established items, especially the location of units, by actual routine inspection in the field.

(*h*) Making final record of the corrected data in the form of sectional maps of the city on a large scale drawn for the purpose, showing all items such as style or type, height, and location of units, together with street characteristics and intensity of illumin-

ation; and the segregation of the final recommended system into steps, such that the immediate expense involved is a minimum and compatible with the requirements; and by the additional future steps the ultimate system can be finally attained.

(*i*) Designing type and plan of distribution system, including routing of circuits underground and overhead, location of transformers, selection of controlling apparatus, cable and other features.

(*j*) Developing special apparatus or applications of standard apparatus to the problem.

Economic Considerations.—(*k*) Calculation of total number of units of each type in each step, and the costs and economies involved in the investment, maintenance and operation of the recommended system.

(*l*) Study of the problem of ownership, rate and order of installation, organization of departments, if city owned, for the installation of initial system or extensions and for their maintenance.

Contractual Considerations.—(*m*) Study and determination of proper basis of contract and length of term of contract.

Legislative Enactments.—(*n*) Suggestions regarding legislative enactments necessary to carry out plans and operations developed in the solving of the problem.

SOLVING THE PROBLEM.

Preliminary Considerations.—(*a*) Zones or Districts.—The city was first inspected by night and by day in the field to determine the character of the streets and the uses made of them, so that zones or districts could be established.

It may be well to have in mind the conception of an ideal city consisting of (*a*) a business center, which originally is small and restricted, and gradually enlarges radially outward through the adjoining residence districts, thereby creating (*b*) a transitory district which is in a state of passing from residence to business district; (*c*) a residence district radially further from the center; and (*d*) an outskirt district, where residences are sparse or not yet built. This ideal form of city is indicated in Fig. 1, but in practise of course is never realized. It can readily be seen, however, that in such an ideal arrangement, the intensity of illumin-

ation required would be greater and greater as the center is approached, each zone or district being most economically served by a certain intensity which is sufficient to take care of the requirements established by the use of the district.

The city of Milwaukee used for illustration in this paper is,

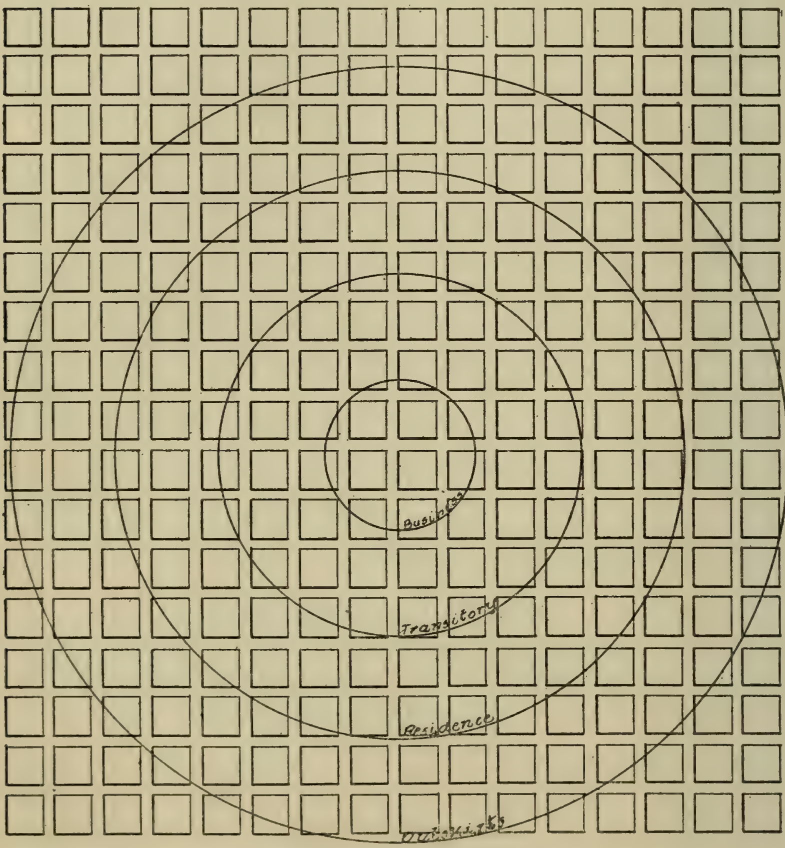


Fig. 1.—Lighting zones of a hypothetical city.

perhaps, as great an exception to the rule as could be found, because of its segregation into several business centers (Fig. 1), practically dividing the city into different isolated communities which merge more or less incompletely into one another.

Affecting this part of the problem, there are also superimposed on the above city plan restricted, or spot, areas, which may be

horizontal or vertical; of considerable or restricted breadth, and considerable or restricted length. These are exemplified by parks, which may be located in any one of the above typical districts, by thoroughfares which may pass through one or more districts, by a boulevard which may pass through one or all of these districts, and which may be a thoroughfare and a park; by squares, which are usually the intersection of two or more thoroughfares, and may include a park; by alleys, which may be present in all districts; by architectural features of the city which need special vertical treatment of illumination, such as the facades of halls and public buildings, fire stations, police stations, and miscellaneous types of buildings; and by monumental features of the city, such as especially artistic public buildings, statuary, fountains, etc.

(*b*-1) Traffic Conditions.—An investigation of the amount of night traffic on the various streets of the city was necessary to determine the intensity of illumination required as well as the mounting height of equipment, since the first purpose of street lighting is safety from collisions. The danger from collision is greatest where the traffic is densest.

Density.—The density of the traffic is the principal factor to investigate, since the number of people involved is in proportion to the density.

Character.—The character of traffic may be divided into two general classes: (*a*) vehicular, and (*b*) pedestrian.

Vehicular traffic may be divided into three classes, at least—(*a*) automobile traffic, (*b*) horse traffic, and (*c*) street car traffic.

The streets and thoroughfares may be divided into at least the following classes, each calling for different intensity of illumination: (*a*) Outskirt streets and alleys, with their generally infrequent use. (*b*) Residence streets, used mostly and comparatively infrequently, by pedestrians. (*c*) Subsidiary traffic feeders, used by considerable numbers of vehicles and pedestrians passing to and through more frequented parts of the city. (*d*) Main traffic feeders, on which the main streams of traffic to and through the business centers are concentrated. (*e*) Promenades, where the densest traffic—especially automobiles—passes in

parade, for pleasure driving or walking and for viewing the interesting sights of the city and each other.

The presence of one or more of these conditions upon the street largely influences the type of unit selected and the intensity of illumination.

(*b*-2) Forestation.—On account of the shadows cast from high units by the foliage of the trees and on account of impracticability of locating a street lighting unit up amongst the foliage or branches, forestation on any given street is perhaps the most rigid restriction with which the engineer has to cope in deciding on the height, spacing, location and type of units.

There are four conditions of forestation, each affecting the problem in a different manner. (*a*) If there are no trees on a street, the problem may be solved without reference to the trees unless it is evident that the future use of the street will bring with it forestation. (*b*) If the trees are very young and slow-growing, the units may be so located as to be unrestricted at least for a considerable number of years. (*c*) If the trees are half grown, with well branching and healthy heads, the restrictions are greatest, as under those conditions in the city referred to, it has been found that, if other conditions demand the street lighting units to be located on the side of the street as curb units, no greater height than 15 ft. (4.57 m.) to the center of the lamp filament is feasible on account of the trees, no matter how strong an argument from the standpoint of blinding effect or light distribution there may be for greater heights. If a cable suspension type of unit is located in the middle of the roadway, a 22 ft. 6 in. (6.85 m.) height of suspension can be secured on the average street, due to the arching of the tree boughs toward the center of the street. These two heights have therefore been selected for their respective types of unit in this city, the latter having a definite ratio of one and one-half times the former, for reasons discussed under the subject of spacings and mounting heights. (*d*) If the trees are old and full grown, their trunks will be high reaching, and the lower boughs either will have been trimmed or fallen off; so that no difficulty is encountered in establishing the 15 ft. mounting height units in proximity to them.

(*b*-3) Existing Poles and Distribution Lines.—A record of existing posts, poles, conduits, distribution lines, gas mains and

services, police and fire alarm systems, street signs, mail boxes and any other aids, or obstacles, to the construction of the street lighting system will be helpful in determining the best, or most economical combination of systems. These should be so considered as to minimize the number of obstructions on the street, as far as feasible, but the engineer should not be too strongly influenced by their presence, to the detriment of the solution of the problem.

(*c*) Intensities.—The required intensity of average illumination sufficient to comply with the different uses of the various districts in the city and with due consideration of all the factors affecting it, as enumerated above, can be determined. This may be stated either in the unit of foot-candles, or in the unit of lumens per running foot of street. Five general amounts of intensity have been selected for this city with variations of them, according to the exceptions to the ideal city lay-out enumerated above. The average intensities selected are as follows: (*a*) Alley and outskirt intensity, 0.01 foot-candle. (*b*) Residence district intensity, 0.03 foot-candle. (*c*) Subsidiary traffic feeder, or thoroughfare, intensity, 0.06 foot-candle. (*d*) Main traffic feeder, or thoroughfare, intensity, 0.12 foot-candle. (*e*) Promenade intensity, 0.50 foot-candle.

Parks, beaches, squares, and other public spaces should be treated according to their use. A general effect equivalent to full moonlight should be provided in parks, etc., except where special use dictates otherwise.

By the following simple formula, those in charge of the detailed planning of the installation of the system, can determine the size of lamp in any given block, or on any given length of street, after the number of the recommended units which will be put in at any given step has been determined:

$$\frac{\left(\text{Length of block in feet}\right) \times \left(\text{Amount of light to be generated for a given illumination intensity}\right)}{\text{Number of units to be installed in the block}} =$$

The size in lumens of the lamp to be installed.

By reference to a lamp catalog, the exact size, or nearest larger size, should be selected.

Lamps, both gas and electric, are now rated in candlepower, lumens, and consumption of energy, such as watts or cubic feet

of gas per hour; and therefore a reference to a lamp catalog will enable the nearest lamp rated in lumens to be selected.

(*d*) Selection of Types of Units.—The type of unit which is best suited for any given street depends primarily upon two general considerations: (*a*) utilitarian factors; (*b*) esthetic factors.

The engineering features of the unit must largely be decided by the utilitarian factors, such as efficiencies of light generation and light distribution, costs, life, maintenance, and so forth. The choice of type of lamp and globes or reflectors must be made principally on utility, if the system is to be economical and efficient, although the factor of greater adaptability to artistic treatment possessed by the incandescent lamp may be taken into consideration; in the types of fixtures and posts the esthetic should be given all the latitude that can be justified.

The choice between electric and gas units is, of course, principally one of utility, and often, as in the case at hand, the one or the other kind may be improved or developed so as to bring them more nearly on a basis of equal utility. This is exemplified by the development of a gas unit for this problem, which possesses practical equality of service and identical appearance with the corresponding electric unit.

Bearing in mind the principles before referred to, indicating uniform illumination effect where feasible, and the engineering factors involved, the following recommendations were made as to choice of lamps and globes and reflectors:

1. Lamps.—(*a*) It was recommended, in this case, that incandescent electric lamps, of the type known as the gas-filled tungsten filament lamp, be used for lighting the streets, except so far as mantle gas lamps may be employed under the conditions covered in recommendation 1 (*b*). (*b*) It was recommended that mantle gas lamps of the new type described later be used in lighting the streets insofar as such lamps may be available in suitable sizes, and insofar as the lighting service provided by such gas lamps can be obtained at a lesser total cost to the city. It was further recommended that a suitable size of gas lamp be considered to be one which will give, with typical service condition of burner but with new mantle, 10 per cent. more light in lumens than that specified for the corresponding size of electric lamp.

2. Globes or Reflectors.—It was recommended that all lamps employed in lighting the streets under recommendations 1 (*a*) and 1 (*b*) be equipped with the prismatic refractor type of globe.

3. Fixture.—From the utilitarian standpoint, the cable suspension type of units (Fig. 10) and other cheaper operating constructions would be indicated, but a consideration of the esthetic precludes the extensive use of such units.

While cable suspension type of units may be somewhat cheaper in operation, or of a higher efficiency of utilization than post types, their utility is greatest at street intersections, and their obtrusiveness less objectionable, and for the reason that no satisfactory looking installation could be produced by utilizing this type of unit at intermediate points along the block—since each unit of this kind requires two poles, one on each side of the street, together with a suspension cable, lowering wires and conducting wires, and an inartistic looking means of supporting the fixture—it was decided to use this type of unit only at certain street intersections, or in few places where unobjectionable, and to make the poles supporting the cable which suspends the fixture of tubular steel and as small in diameter and simple in construction as would serve the purpose, thereby making the units as unobjectionable as is feasible. Unformed wooden poles, or posts, ugly mast-arms, and other similarly utilitarian, but inartistic equipment, can no longer be afforded in a city which is building for its future and taking cognizance of the esthetic side of civic work. Incandescent lamp fixtures patterned to imitate gas lamp casings, while perhaps justified from the manufacturer's standpoint by the strong transitory demand, cannot be considered as meeting both sides of the problem.

In considering the artistic factors in the selection of the types of units, recognition should therefore be given to the rapidly growing attitude of the citizenry of this country toward a greater appreciation of simple and practical art in connection with civic matters, and to this end the assistance of a committee consisting of architects or art experts, appointed by the American Institute of Architects or similar society, can be obtained and their hearty cooperation in selecting and designing types of units should be utilized in this work.

In residence districts and in forested boulevards, on account of the trees and esthetic factors, except at the intersection of the residence streets, where greatest illumination efficiency can be obtained, at a lower illumination cost, from a fixture suspended at the center of the intersection, a post type of fixture mounted 15 ft. (4.57 m.) high, on one or both sides of the street at the curb, best complies with both factors (*a*) and (*b*). As stated before, higher mounting heights than this are not here practicable.

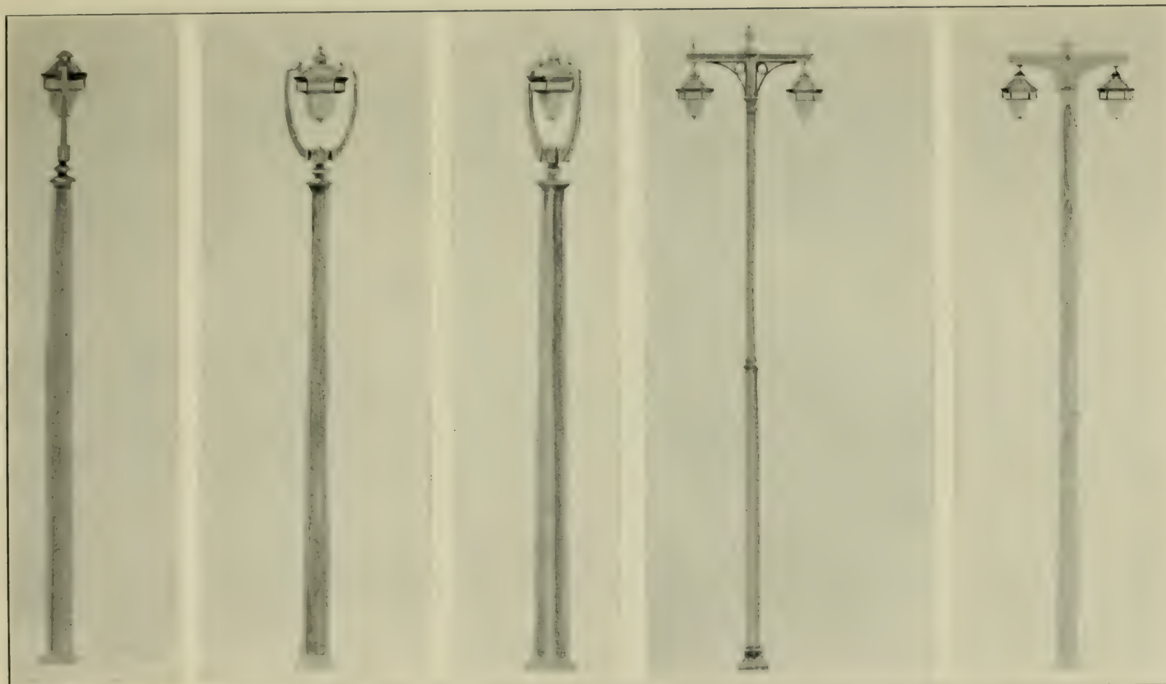
In the transitory districts and growing business districts, the stores are usually of lesser number of stories, built up to the sidewalk line, and the residences are usually relatively small and near the sidewalk. There are often no trees on these streets, or it can be anticipated that in the near future the few remaining ones will be eliminated, as the natural growth of the city demands it. Therefore, units of higher mounting height can be installed at these points. The esthetic restriction, however, is one which demands that the units be not suspended far above the roofs of the buildings.

Practically the same conditions prevail on the subsidiary traffic feeders which radiate out through the residence districts and are in a transition from the residence type to the business type of street, or have settled down to the small store business type.

Therefore, post type of fixtures, hung pendent 22 ft. 6 in. (6.85 m.) high, have been selected for a district of this class. Single or double brackets may be used. (Fig. 7 and Fig. 2, *d* and *e*.)

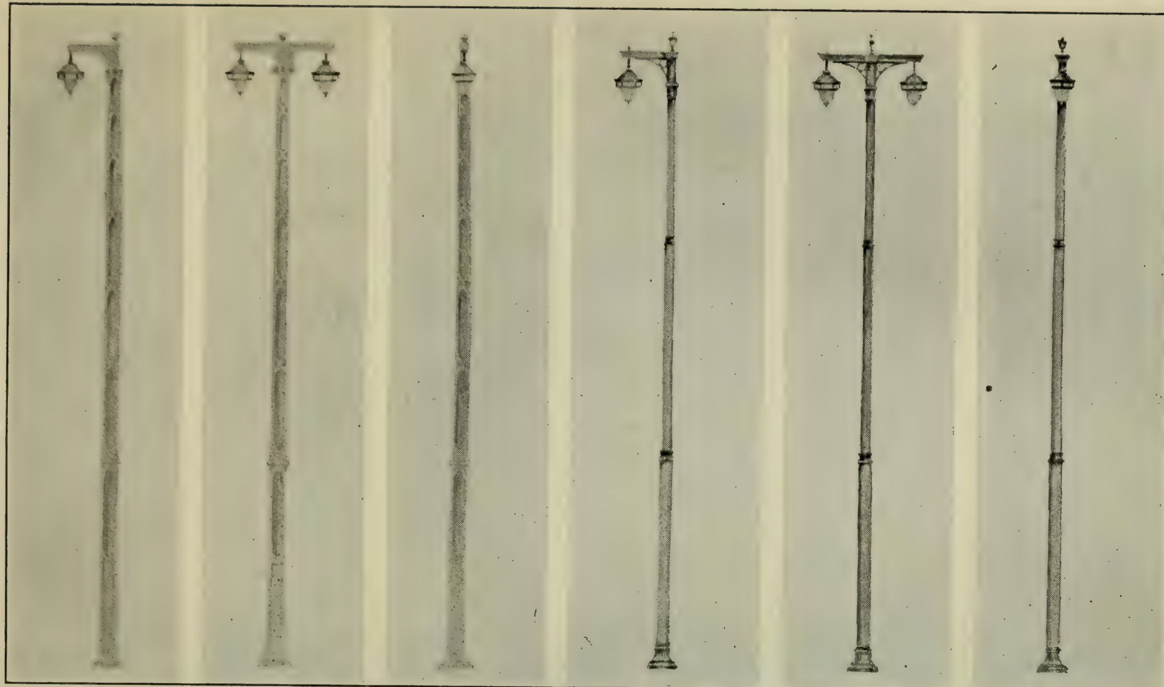
In the main business districts, on unforested boulevards, on important thoroughfares, and in parks, where there is no restriction due to forestation or low building heights, the engineering considerations of minimum investment, best distribution, minimum blinding effect, and best appearance have led to the choice of post type fixtures at 30 ft. (9.14 m.) mounting height with single or multiple brackets, as desired. (Fig. 8 and Fig. 3, *a* to *f*.)

In large open spaces in parks, on public squares, on bathing beaches when illuminated by street lights, the same considerations lead to the choice of post type fixtures and 45 ft. (13.71 m.) mounting height.



a *b* *c* *a* *e*

Fig. 2.—Photographs of original wash-drawings of lamp posts; *a*, *b* and *c* represent 15 ft. concrete posts for gas or electricity; actual installation shown in Fig. 6; *d* represents a 22 ft. 6 in. tubular steel and *e* a concrete post.



a b c d e f

Fig. 3.—Photographs of wash-drawings of lamp posts; *a*, *b* and *c* represent a 30 ft. concrete post; an actual installation is shown in Fig. 8; *d*, *e* and *f* represent 30 ft. tubular steel poles; no installation of this type post has been made.

Units of this height, equipped with two, three, or four brackets, and very few in number for the area covered, are used at these points, where unobstructed open space is the principal characteristic, to obtain a uniform illumination of the area with almost unnoticeable source on account of its height, and these units simultaneously act as beacons, serving to locate these areas from considerable distances.

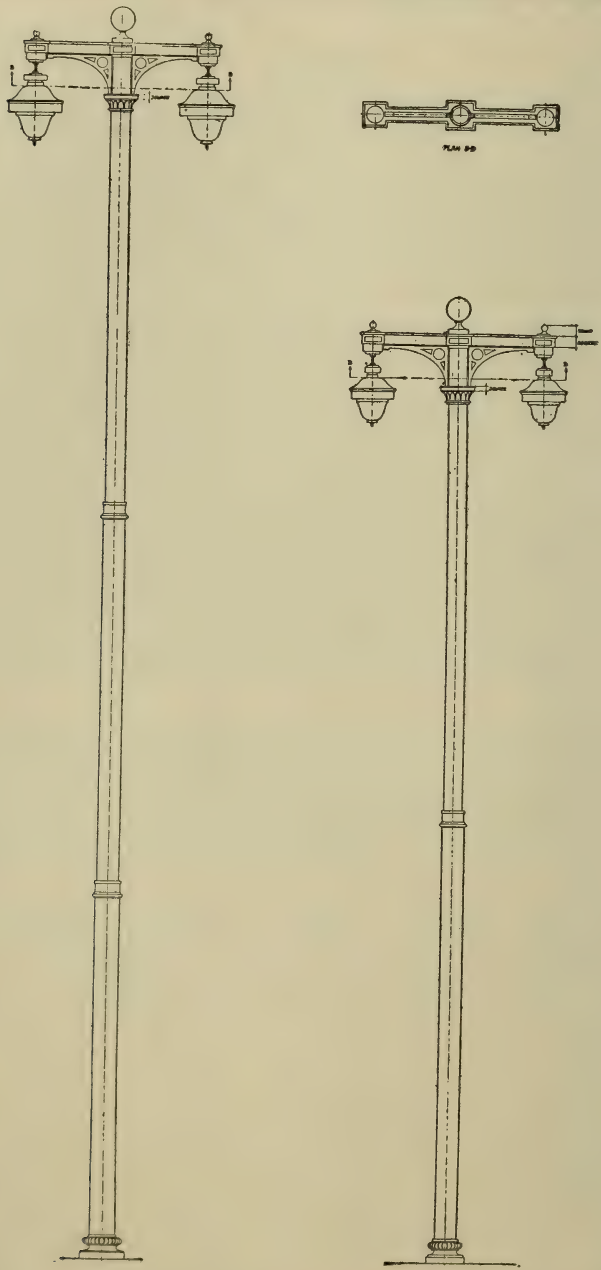
The standard heights have been selected as stated before, with definite ratios to one another, being, respectively, 15 ft., 22½ ft., 30 ft., 45 ft., with respective ratios of 1, 1½, 2 and 3.

It was therefore recommended that the types of street lighting fixtures shown by the artist's drawings, Figs. 2, 3 and 10 be adopted. These types have been especially designed by a committee of the local chapter of the American Institute of Architects to meet the requirements of the City of Milwaukee. The actual installations are shown in Figs. 6, 7, 8 and 10.

Bathing beaches, tennis courts, statuary, and building facades can often be most economically and effectively illuminated by flood lighting, in which cases special treatment is, of course, called for.

4. Posts.—(*a*) It was recommended that for the main business district, that for certain main streets, that for certain boulevards, and that for the general lighting of certain parks, a post of the types shown in Fig. 8, and supporting the lamp at a height of 30 ft. above the street surface, be employed. (*b*) It was recommended that for business streets and business districts other than the main business district, and for certain non-forested streets, a post of the type shown in Fig. 7, supporting the lamp at a height of 22 ft. 6 in. above the street surface, be employed. (*c*) It was recommended that at the intersections of residence streets and in transitory districts, suitable tubular steel poles of the type developed (Fig. 10) be employed, the lamp and fixture (Fig. 15) being supported by a messenger cable at a height of 22 ft. 6 in. above the street surface. (*d*) A post supporting a lamp at a height of 15 ft. was recommended for installation between street intersections on long residence blocks and on certain boulevards (Fig. 6).

The 15 ft. post unit was recommended to be supplied with concrete posts; the 22 ft. 6 in. and higher units can be supplied



4 5

Figs. 4 and 5.—Plans of lamp posts; Fig. 4 represents a 30 ft. tubular steel post, and Fig. 5 a 22 ft. 6 in. post of the same kind.

either in concrete or in tubular steel, the preference being given to concrete, if a satisfactory price and mechanical features are secured.

Engineering Considerations.—Installation Factors.—The factors going to make up the success of an installation for the purposes of street lighting can be divided into three classes: (*a*) Factors affecting investment; (*b*) Factors affecting maintenance; (*c*) Factors affecting energy supply.

Factors Affecting Investment.—Since before a street lighting system can be installed, material and labor have to be purchased for the different parts of the installation, a considerable investment must be made, and interest and amortization arrangements be concluded before the system is installed ready to operate. This is a financial or banking function, which can be assumed by a public utility, the city or an individual, such as a contractor, the choice between them being a matter outside of the illuminating engineering problem. The necessary and ever-present investment charges, however, must be met, whether assumed by the city itself, or arranged for at a profit to the public utility or contractor.

Factors Affecting Maintenance.—After the system is installed and paid for, it must be maintained in a physical operating condition, and such matters as lamp renewals, pole painting, repairs, cleaning and replacement of glassware, etc., must be paid for and accomplished. This again may be done in any of three above ways, depending upon the desire and ability of the city.

Factors Affecting Energy Supply.—A street lighting system, even after being installed and properly maintained, must, to make it useful, be supplied with some sort of energy to produce the light of the lamp, and this energy supply must be reliable, efficient, and of good quality. It can, of course, be supplied either by the city or by a public utility company, the effect as far as illumination of the street is concerned of one source of supply or the other being absolutely immaterial for equal quality of energy supplied. The decision as to whether to use gas or electricity and the willingness of the city to go into the business of manufacturing gas, electricity, or both, of course, has a bearing on the source of supply.

Investment Factors.—Affecting the size of investment are such

factors as the unit, distribution system, and source of supply of energy.

(*e*) Adaptation or Design of Units.—The desirability of the development of special types of units for this problem was felt to be apparent by the committee and engineer after a study of the scientific and esthetic requirements of street lighting units as set forth in the establishment of scientific principles and a comparison of the present marketed units with these requirements, together with an inspection of the available designs of posts and fixtures offered by manufacturers to-day. The aim of all individuals connected with this design work was to secure artistic simplicity, combined with their interpretation of utilitarianism and good engineering, with due consideration of the cost.

The incandescent electric lamp chosen, in its various sizes, is readily adaptable to forms complying with the utilitarian and esthetic factors, and could, alone, fulfill all the requirements for the city; but since a gas system can scarcely be expected to fail as a whole, except in dire emergencies, gas lamp outages are encountered as individual cases only; the whole system or any large portion of it never being out at any one time, which is not, under past methods of construction and operation, true of an electric system. Therefore the gas lamp would have considerable advantage if used in combination with the electric system, on account of the double insurance, as to continuity of service, accruing from the use of the two systems.

There is, also, almost the same ability to reflect and refract the light from the gas mantle, as in the incandescent electric lamps, thus securing the same type of light distribution curve as is obtained from the incandescent electric lamp, and making it possible, therefore, to distribute the light with equal advantage on the street, if its possibilities were developed.

The possibilities of the gas, if properly developed, were thus fully recognized, and so that the city might have the advantage of the choice between the two sources of energy, or so that they might have a combination of the two and be benefited by the competitive prices and double insurance involved in the choice between the two types; a great deal of inventive design and development work has been done in order to have a gas unit

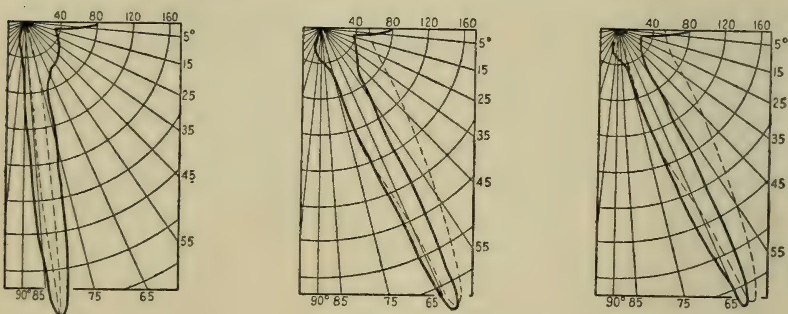
brought out which will compete satisfactorily from an engineering standpoint with the proposed electric unit.

Through the engineer, in cooperation with the city and the gas utility companies, a residence district post type unit of 15 ft. mounting height has been developed to give equally satisfactory engineering results as to illumination on the street with the electric unit of practically the same lumens capacity and it will, to the layman and probably to the expert, look exactly the same on the street whether fed by gas or electricity (see Fig. 6). In other words, the residence unit recommended is identically the same for gas or electricity, except for the following points: the substitution of gas for electric wires in the conduit in the post, the substitution of the gas burner for the electric socket and of the gas mantle for the electric lamp. The post, fixture and refractor have all been designed so as to be amply large and scientifically correct for either gas or electric lamps.

This makes it possible for this city to obtain equitable competition on both gas and electric units of this character for the residence and similar parts of the city, and to enjoy the flexibility of being able to substitute gas for electricity or electricity for gas, in these units, without any large expenditure for the change.

The general type of the refractor does not need description here, but a new development of it for this problem may be of interest. At the beginning of this survey, there had shortly before been placed on the market two sizes of this type of refractor, and on investigation it was found that the smaller one of these could not be used for this problem, and that the large one, measuring approximately 8 in. (20.32 cm.) across the top, met only several of the requirements. In cooperation with the city, the manufacturer and the gas utility companies, therefore, the engineer was able to have developed a specially-shaped, larger size refractor, measuring approximately 11 in. across the top, which admits of the use of the larger sizes of incandescent electric lamps and the gas unit recommended above. It meets the artistic requirements of the problem on account of its increased size and its shape and meets the engineering requirements not fulfilled by the 8-in. size. It is more efficient at certain angles, and lends itself more readily to the closer spacings.

Several samples of this new refractor have been made and tested. With these two sizes (8 in. and 11 in.) available, all the varying conditions of spacing, heights and other considerations can be satisfactorily met. The curves of light distribution from a unit equipped with an electric incandescent or gas lamp and this refractor more nearly approximate the prototype curves than those of any other unit, and these curves can be conveniently varied so as to throw the maximum ray out further from the base of the unit (Figs. 12, 13 and 14) by merely lowering the lamp slightly further into the refractor, thereby making it possible to direct the light where desired, especially when installed in a fixture having adjusting features such as that developed for this city and described below.



12 13 14

Figs. 12, 13, 14.—Light distribution curves from a refractor of special design with the lamp in several positions.

The engineering requirements as to height above the street, the limitations of the physical size of the refractor and lamp, and the requirements to be met by the artistic considerations controlled by the different characteristics and uses of the street, combined with an effort to adequately meet the requirements established by principles already outlined, made it desirable to devise and design different types of fixtures for the different districts, streets, etc. Therefore the fixtures shown in the accompanying photographic illustrations (and Fig. 15) are the results of valuable work done by the Committee of Architects from the artistic side and engineering and mechanical features devised as a part of this survey, some of which are protected by patents of the city.

Some of these novel features may be mentioned: A system of ventilation of the lamp base and socket and supplying air to the

Fig. 6.—Installed, 15-ft., concrete gas or electric lamp post.

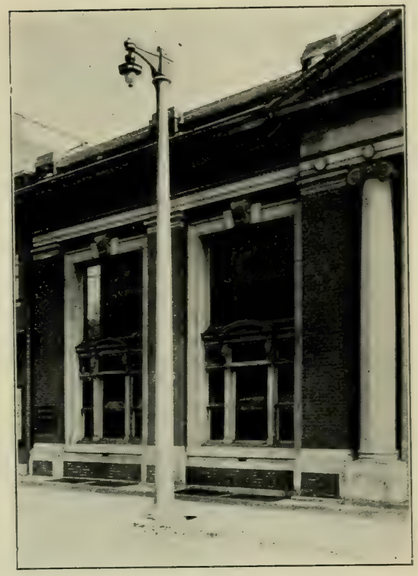


Fig. 7.—Installed, 22.5-ft., concrete post for electric unit.

Fig. 8.—Installed, 30-ft., concrete post.

Fig. 9.—Transformer ready for covering.

Fig. 10.—Installed cable suspension unit, 22.5 ft. high.

Fig. 11.—Night view of Grand Avenue Boulevard, Milwaukee.

gas lamp; adjustable parts to raise and lower the lamp in the refractor to vary control of light; artistic design; combination bug screen and reflector, etc. (Fig. 15.)

The proper height at which to mount the lamp having been determined, and the design of fixtures necessary to hold the electric or gas lamp and refractors in proper relation to each other having been made, it was then necessary to complete the engineering design of the proper post for 15 ft., 22 ft. 6 in., 30 ft., 45 ft. mounting heights, and the corner suspension poles, to act as suitable supports for these fixtures at the respective heights. These were designed as already set forth, the main factor being borne in mind,—that it is dsirable to mount a lamp as high as it is feasible under the engineering, financial and artistic limitations set by the conditions of the problem.

The high mounting heights are desirable if the economy of minimum glare is to be secured, this factor being discussed at considerable length in an article by Sweet[1] in the *Electrical Review* of March 6, 1915. The forestation is the greatest limiting condition.

In the design of these posts, the Architectural Committee has again been helpful in combining the engineering features with artistic simplicity.

The posts for the taller units, shown in the accompanying illustrations, have been designed for construction from two kinds of material, namely, tubular steel and concrete.

The post for the 15 ft. unit is designed in concrete only, as this material is coming more and more largely into use, makes a perfectly formed shaft of any design required, is practically free from deterioration when exposed to weather conditions, is decreasing in price, as the manufacturing details become better understood, instead of increasing, like wood; presents the best appearance of any material when properly designed, moulded and finished; and with necessary reinforcements is practically indestructible and will not snap off and fall to the street when given a heavy blow.

Upon the adoption of these post and fixture designs, an ordinance can be passed requiring that no street lighting post,

[1] Sweet, Arthur J., Glare as a Factor in Street Lighting; *Electrical Review and Western Electrician*, vol. 66, No. 10, 1915, p. 439.

whether installed or owned by private individuals, or the city, except it be the standard design, shall be placed upon the streets, thus standardizing the units throughout the city, and avoiding the conglomeration of designs now placed on the street according to the whim of an individual or group of individuals, to be abandoned later, when the novelty has worn off, or allowed to stand unlighted on account of excessive expense. Through an ordinance of this kind, the combined cooperation of the merchants and the city can secure, through a division of the burden of expense in some manner, a combination street lighting and advertising result which will be creditable. Ordinances of this kind are in force in other cities.

Before leaving this subject, attention should be directed to the use of these units in connection with street naming signs. It is also contemplated that the translucent glass windows at the top of the fixtures can be used for street sign purposes. For instance, since the fixture is hexagonal at the top, the window parallel to the street might have the number of the house nearest to which it stood printed on it, and the window to the right, say, have a + sign, or arrow pointing up (↑) to indicate that the numbers increased in that direction, and the one to the left have a — sign, or arrow pointing down (↓) for the opposite purpose, thereby facilitating the location of addresses by night or by day. Other combinations will suggest themselves.

It was proposed that the lamp transformer, the use for which will be explained in the discussion of the distribution system, be included for this case as a part of the post equipment, since it is proposed to bury this transformer in the ground at the base of the pole, or in a cavity in the concrete foundation, making it a part of the complete unit.

These transformers are thoroughly insulated to stand 15,000 volts or over, and are at least as dependable in this respect as the cable, which is also buried in the ground, and it is therefore intended to place them in iron or other type of cases, thoroughly impregnate them with insulating compound, filling the entire case with this compound, and to place the case containing the transformer underground at the base of the pole, surrounding it with a thin shell of concrete after thoroughly pro-

tecting the case against corrosion. In the remote emergency that trouble might occur in these transformers, they can be excavated and replaced and repaired in a manner similar to the method of repairing cable. Transformers of this type are now largely and successfully used in manholes with practically no occasion for inspection or repair.

Since the above described lamp transformers reduce the current from relatively high voltage to the voltage of the lamp or lamp circuit, which never reaches 50 volts, considerable economy can be obtained and a much easier method of wiring the post devised, by the use of this transformer, and there will thus be no high voltage applied to the unit itself and no danger will therefore be present to the citizenry or to the workmen delegated to renew the lamps, clean the equipment or repair parts. It is therefore proposed to run from the secondary terminals of these lamp transformers an unarmoured, lead covered, rubber insulated, duplex wire, through the pipe running through the center of the post, and connect this wire directly to the socket inside the fixture, thus making a simple and complete connection from the transformer to the lamp. Of course, in the case of gas units, the above described transformer and the wiring just referred to will be entirely eliminated.

The wiring of the cable suspension type of unit will be somewhat different in detail where raised and lowered. A special combination supporting and conducting cable has been developed for this work, eliminating two unsightly wires.

(*f*) Spacing and Locating Units.—Having decided on the proper type of lamps, fixtures and posts, with wiring and transformer equipment, the next requirement is to locate the proper types of units on the streets of the particular districts for which they are suitable. The spacing of any particular type of unit of a particular height is entirely dependent upon definite mathematical relations between the spacing distance and the mounting height for a given degree of uniformity of illumination along the street. (See *Journal of the Franklin Institute,* Vol. CLXIX, No. 5, "An Analysis of Illumination Requirements in Street Lighting," by Arthur J. Sweet.) In other words, there is a definite ratio, which

is designated by the letter M, between the spacing distance between units and the mounting height of the lamp above the street for any given type of light distribution curve and any given degree of uniformity striven for. Having determined the type of unit to be placed along any block, which is governed so largely by the class of district or zone to which the block belongs and the forestation, the units are first theoretically located on maps

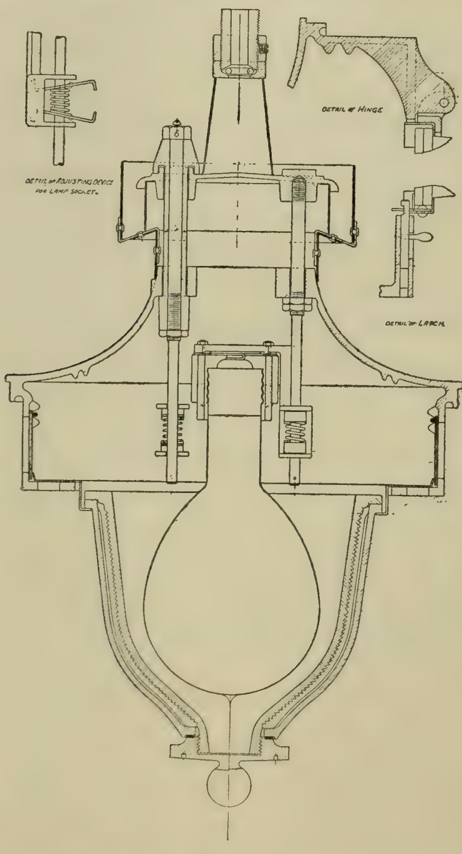


Fig. 15.—Diagram of lighting fixture equipped with a standard reflector, used on the 22 ft. 6 in. concrete post.

prepared for the purpose by dividing the block into as nearly theoretical parts as its length will allow.

The ideal condition ultimately to be obtained by this spacing is one of practically uniform illumination along the entire street

surface, and the spacing has been arranged with this idea in view. For any given value of M, or ratio between the spacing distance and the mounting height, it, of course, is apparent that the higher units will come at greater distances apart and the lower units at closer distances. For example, 15 ft. units 8 times the mounting height apart (ratio $M = 8$) will be spaced 120 ft. apart, while 30 ft. units spaced 8 times the mounting height apart (with same ratio, $M = 8$) will be spaced 240 ft. apart, with equivalent results from the standpoint of uniformity.

Maps give the number of units of each type used throughout the city and their approximate location both in the proposed minimum present installation and the ultimate system proposed. These maps give the type of unit to be used on a given street in any given district, the number of units per block, the side of street, approximate location and in which one of the four progressive steps it is recommended the unit be included.

(*g*) Checking Location of Units.—After the theoretical spacings have been laid off on the maps, thus locating the units in their ideal position, it was necessary to check these locations on the street and to adjust them according to best engineering so as to avoid such physical interferences as driveways, walks, poles, etc., and to make a practical layout as near the ideal as feasible.

In connection with this adjustment, due consideration was given to the placing of the units on lot lines, between houses, in order to take full advantage of what light is emitted toward the houses and lots—which light might otherwise be objectionable or wasted—for obtaining police protection by illuminating the space between the houses. It was here too that considerable attention was given to the lighting of the alleys, so that light will be thrown down the alleys instead of on the fronts of the houses and buildings.

(*h*) Final Records.—Large-scale sectional maps, compiled in a street lighting atlas, give detailed corrected information minutely and graphically, with other details as explained in the accompanying keys. These form a guide for proceeding with the installation at any rate of speed which may be attempted, with a complete plan as to future steps, assuring that each step is in the direction of an ultimate system which will adequately light the streets for

many years, regardless of the probable advance of the science of street lighting.

On these maps, which are of white cloth with street lines in orange for non-interference, are shown by rubber stamps, the residences, stores, chruches, office buildings, factories, fire stations, schools, public buildings, etc.; the trees; the street cars; the density of traffic by the number of automobiles shown per block; the type and location of street lighting units; exact corrected distance between units; serial number of each unit, showing the step to which the unit belongs, and the number of generated lumens per running foot of street in each block. These maps show at a glance the type and locations of all units, and by indicating the character of street and forestation, and the location of special buildings, indicate also the reasons for the choice of type and location of each unit.

(*i*) Type and Plan of Distribution System.—With the complete unit, whether gas or electric, installed, the next step would be to connect them by means of service connections through the distribution system, whether gas or electric.

The usual type of electric distribution system employed up to the present time has been one of the several forms of high voltage, constant-current, separate and distinct street lighting distribution system which requires a different type of apparatus at the station from that used for transforming and distributing current for the domestic use or industrial use and which is idle during all the daylight hours of the year, involves additional investment, carries the burden of unused capital, requires additional attention and loses the value of load and diversity-factors in many cases. Separate feed wires are in these cases required to be run from the station to the street lighting circuits covering the district to be lighted and these wires or cables occupy room in the ducts or on the cross-arms of the overhead lines.

In many cases, and, in fact, usually, when a district is ready to receive attention of the city for street lighting, it means that residences have been built in this district and probably domestic electric service has been run into the locality and is available. The usual street lighting service, however, is often not available and if the district is added to the present lines it may mean con-

siderable rearrangement of circuits and new apparatus.

The past systems are also almost always of a dangerously high voltage requiring expenditures for film cut-outs, cut-out pulleys, highly insulated cables in the poles or posts, and involves the accompanying dangers to the lives of the citizenry as well as the trimmers and attendants, and the attending troubles accru-

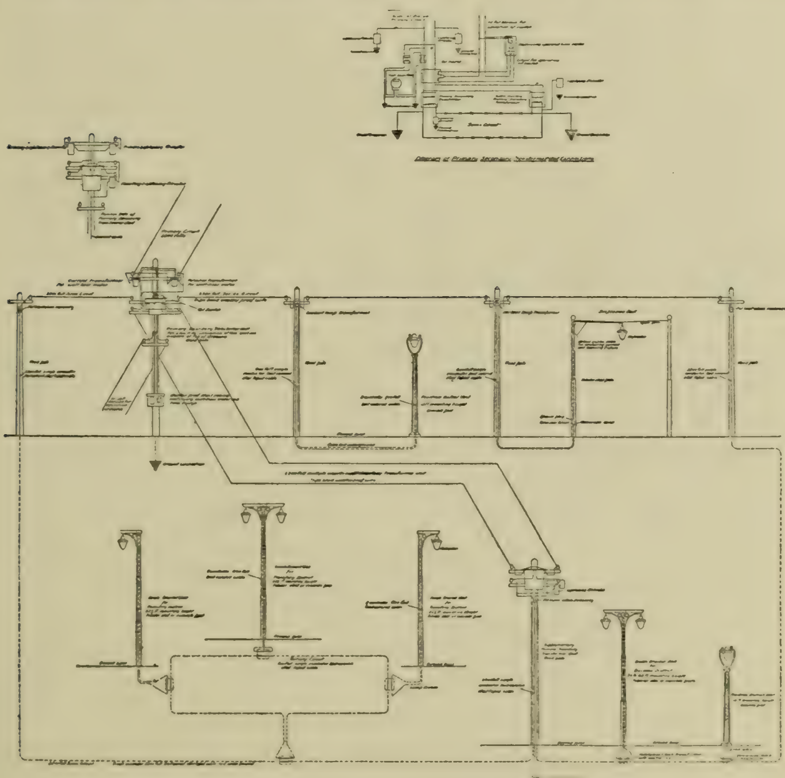


Fig. 16.—Plan of circuits and location of apparatus.

ing from high voltage. It is believed that all of the objections to the present type of system can be overcome by treating the street lighting load logically and assuming the conditions to be similar to those governing domestic or industrial service, where a given load is attached to the regular service line.

The type of street lighting distribution system devised and recommended here is, therefore, founded on this idea and consequently departs radically from the present type. A sketch show-

ing the typical lay-out of the circuits and the general typical arrangement of apparatus is given in Fig. 16. This figure is practically self-explanatory, but a short summary description had best be given.

Any sources, consisting of alternating current primary lines, which enter the districts to be lighted, can serve as feeders for this system. They can originate in a public utility company's plant or in a municipally owned power plant, the only restriction being that it transmit alternating current of a standard lighting frequency, so that transformers may be designed to operate on it. This current is used almost entirely for the greater part of the city. These primary circuits should be carried to the points of service delivery, which is recommended to be in each case on a separate pole, distinct from the rest of the lines and located in an alley at the most convenient point in the district for cutting into the street lighting circuit.

On this pole will be placed primary and secondary line lightning arresters for protecting the apparatus; one or more multiple-multiple type transformers, having various taps on its secondary to take care of the varying number of lights in the district; an electrically controlled pole type oil circuit breaker for automatically cutting out the transformer in case of trouble and for turning on and off the lights in the district by means of a time switch mentioned later. The time switch and oil switch may be combined in one apparatus. To avoid the necessity of an operator turning on and off the circuit, and to make them positive in their operation, the self-wound time switch, which has been developed to a thoroughly dependable point, has been selected. In order to get the correct and accurate measurements of energy supplied to the street lighting system, a watt-hour meter may also be included in this equipment,—the necessary current and potential transformers being placed at the top of the pole and the watt-hour meter and time switch being placed at the bottom of the pole in a metal cabinet, locked, and conveniently arranged for inspection and reading.

This equipment will transform the ordinary primary circuit current to that required for street lighting, will turn the lights on and off at predetermined times, measure the energy supplied to

the street lighting system and protect the transformer and apparatus from overload and lightning.

From the secondary of the primary transformers will be run a series secondary circuit, consisting of a single wire loop run on poles overhead in some cases but using, in 88 per cent. of the installations, single conductor, rubber insulated, lead covered, steel taped cable buried under the sod in parkways, and under the blocks, asphalt or macadam of other thoroughfares.

On this secondary circuit no lamps will be connected directly and in some cases an additional tertiary circuit may be run by the installation of a (secondary) series-series transformer, which will receive a tertiary circuit running to the lamp location and connected to the lamp transformer.

The lamp transformers, or tertiary transformers, may be connected directly to the secondary circuits as shown in the diagram or to the tertiary circuit, according to the conditions. These series-mutiple lamp transformers feed the lamp circuits.

It will be noticed upon an inspection of the diagram that relatively low voltage cables can be used in most of the installation and that only medium voltage will be necessary at any point. As before stated, in the post and lamp itself, the voltage is practically negligible and no danger from troubles or accidents at this point can be encountered.

By the use of this scheme, it is believed, many advantages are gained, such as savings due to low cable-installation cost; due to elimination of ducts; due to inexpensive wiring at the post; elimination of film cut-outs, windlasses, pulleys, cut-out pulleys, high voltage at poles and elsewhere, etc.; these results can be accomplished by the installation of inexpensive small transformers, reducing the voltage to a point where there will be less maintenance troubles and greater safety.

While in the above-given typical layouts, rubber insulated lead-covered, steel-taped cable buried without ducts, is recommended, full consideration has been given to the fact that in many districts of the city, public utility ducts with cables at present exist, and that there are also certain conduit systems of the city's fire and police departments, which could be used for this purpose. In this particular case it was found, however, that the large number of new manholes and laterals required to obtain egress from the existing

ducts, together with other considerations and the advantages of the recommended plan, made a separate system the most feasible.

Having decided on the type of distribution system to be used, the next problem was to apply this to the districts or zones referred to earlier, and to lay out the circuits in the most economical manner so as to connect up and include all the lamps in any given district. For this purpose it was deemed most practical and desirable to divide the city into definite unit areas of approximately the same size (Fig. 17), to select a point near the center of the area, consider that the primary circuit was available at this point, set the pole containing the described apparatus at this point and run a secondary circuit so as to be available for all ultimately required units and then lay out the tertiary circuits and lamp circuits required for each step so that a system plan results which will have a present lay-out of secondary circuits to take care of the ultimate number of lamps by the mere banking of primary transformers and the cutting in of additional secondary and lamp transformers, as units may be added. (A map of these circuits should be made for record.)

Maintenance Factors.—The cost of maintenance of the system as proposed should be a minimum.

(*j*) *Application of Standard Apparatus.*—The distribution system is composed of material well standardized and of greatest durability and dependability. Although the collective use of the various materials and the way in which they are adapted to the system may be quite novel, almost all of the apparatus used is not in an experimental stage of development. Any novelty of the scheme is in the arrangement of the apparatus. Since this arrangement tends towards simplicity and low voltage with high factors of safety, once the system is installed, its maintenance cost will be low.

It is believed that the plan and procedure recommended is merely an advance interpretation of the trend of the present revolution of the science of street lighting—an interpretation of the "handwriting on the wall," perhaps—but nevertheless a thoroughly practical culmination of the many years of development and standardization in this and allied fields, which Milwaukee is in the unique position of being able to adopt more

completely than any other city, since most other cities have been able to adopt only isolated portions.

Lamp Renewals and Cleaning of Glassware.—The renewal of the lamps and the cleaning of the refractors will be accomplished from a tower truck, similar to that used in repairing electric railway trolleys. This is thoroughly feasible on all streets having good pavement, that is, at least in the business districts, transitory districts, thoroughfares, parks, etc., and it is planned for the streets where pavements has not yet been installed, or where the snow may lie long enough to prevent the operation of such an equipment, to have the cable-suspension units lowered by means of a certain arrangement of combined lowering cable and conducting cables, indicated in the schematic diagram of the typical arrangement of circuits. By this plan it is believed, the lamp renewals and refractor cleaning costs can be minimized.

Outages.—When a sufficient or adequate number of units has been installed, especially if a combination gas and electric system is decided upon, it is intended to do no unnecessary repair work on the live circuits, although work could be done if necessary, because of the very low voltage at the lamps, and therefore any lamps out individually could be allowed to remain out one night because there would be sufficient lamps still burning to very adequately illuminate the street. In case an entire circuit were in trouble, of course, the circuit could, if necessary, be cut off at the primary transformer or switch and the repairs made without danger. Due to the extended use of low voltage in this system, and almost entire absence of the higher voltages, and the installation of cable which will give a large factor of safety, the breakdown trouble should be minimized. Due to the use of transformers as proposed, an outage of one lamp will not affect the rest of the lamps, as in the case of a series circuit. Thus each electric light is almost independent and individual, and approaches the reliability of the gas units. The outage should be low. The reduction in energy for it, when it does occur, is properly deducted by the watt-hour meter.

Maintenance Requirements.—(1) It was recommended that incandescent electric lamps be renewed when burned out, or when the amount of emitted light has dropped to less than 80 per cent.

of the initial value. It was further recommended that mantle gas lamps be required to be maintained so that the total amount of light emitted by any lamp shall not drop below 70 per cent. of the initial requirement. (2) It was recommended that the lamp and the fixture parts, and particularly the prismatic refractor, be thoroughly cleaned at least as often as once a month, on the average. (3) It was recommended that all metal posts or poles be painted at least once every two years.

Energy Supply Factors.—Since the ordinance which instigated this survey called for a comparison of the availability of various illuminants, this matter has been considered very thoroughly. Two types of energy are feasible for use in the lighting of the streets of this city. Electricity is, of course, one of them. No arguments are needed to convince one that electricity should be considered.

As cited earlier, at the beginning of this survey, it was felt certain that electricity would be the only feasible type of energy to be used for the kind of scientific street lighting system to be proposed, unless something different were to be developed in the way of a gas unit than the units available on the market to-day. Since the necessary gas light development has been accomplished, gas units will be accepted wherever applicable within the recommendations under "Lamps" and "Maintenance Requirements." It is therefore practicable to light the streets in this case by the use of either electricity, or electricity and gas combined.

Source of Energy.—It will be apparent from a perusal thus far that the system recommended can be operated from a source of energy producing current under municipal ownership or under private ownership, and, regardless of whatever decision will be made as to the present or future supply of electricity or gas from a municipally owned plant, the street lighting system proposed will be equally adaptable.

If the system is to be entirely electrical, as has been pointed out, the electricity should be considered delivered to the circuits in their respective districts, and the distribution system has been calculated on this basis. It will be apparent that the electricity could be manufactured by either a municipally owned plant or a privately owned plant, without in any way affecting the illuminating efficiency of the street lighting system.

In case it is deemed advisable for the double insurance or reliability of service, or in case the price submitted by the gas utility company is attractively low, gas may be used, as has been before stated, in large portions of the system.

Economic Considerations.—(*k*) Costs and Other Data.—The next step is to prepare tabulations of data on unit and total costs involved in the construction, maintenance, and operation of the system, and a compilation of tabular numerical data segregating the material and other items on forms for ready reference.

(*l*) Ownership and Maintenance.—The problem of who should own and maintain the street lighting system is one deserving thorough investigation and involving many economical questions and local conditions. After a thorough consideration of the entire subject, the decision in this case was reached that the city should own the distribution system, comprising cables, transformers, posts, fixtures, lamps, and other apparatus already described. It was also recommended that the city maintain the entire system as just described, if city owned, through the organization of a division or bureau of its public works department. In the case of the gas units, it was recommended that city ownership extend only as far as the gas service pipe and that maintenance be contracted for with the gas utilities, the city department to have inspectional and supervisory charge of the maintenance. In either case it was recommended that energy be contracted for with the public utilities.

Contractual Considerations.—(*m*) Basis and Term of Contract.—The features of a street lighting contract are also of utmost importance in a problem of this character and while not affecting the illumination or engineering problems, should certainly receive the strictest consideration. Any one of three contractual arrangements could be made, by which the electricity could be obtained for the operation of a system.

The city might (*a*) construct and own the plant and the street lighting system; (*b*) might own the street lighting system only, including only the distribution system and units, as herein outlined; or, (*c*) might make a contract with the public utility to construct a system, maintain it and supply it with energy.

The usual form of contract, for street lighting service, used in the past, has been that using a "per lamp per year" basis, in

which a city pays a fixed and definite sum per year for each lamp operated, without any stipulation as to the portion of this amount paid for investment, maintenance or energy charges.

There is a tendency at present to devise other forms of contract between the city and public utilities to take its place. A public utility company is really in the business of the manufacture and sale of electricity, or gas, or other public utility product, and should be interested primarily in the sale of that product. In the per-lamp-per-year type of contract, the public utility usually made the investment in the labor and material necessary to install and construct the system, paid all investment charges and depreciation charges, and was quite properly paid for this function as a part of the rate,—in other words, it acted as the banker supplying the capital or financial backer in the proposition. It also maintained and repaired and operated the system, as far as routine turning on and off of lights, trimming of lamps, repairing wires and other parts of the system are concerned, in acting as maintainer of the equipment. It also acted in the natural capacity of the public utility, in furnishing the energy supplied to the lamp in the same manner that it supplied current to its domestic and industrial consumers, only by an entirely separate and distinct set of apparatus and distribution system.

The "per-lamp-per-year" charge is, in this form of contract, not segregated into what the city is paying the company for acting as banker in the proposition, or what it is paying for the maintenance of the system, or at what rate it is being furnished the electric current or gas for use in the system. The flat figures named in the "per-lamp-per-year" contract most naturally and quite properly include enough to pay, or nearly pay, the public utility company, during the term of the contract, for its investment in the special equipment at least.

In the present case, as designed and laid out above, or wherever the distribution system is to be owned by the city, it would seem to be most feasible for the city to make its own investment in its distribution system for street lighting and buy its energy supply. The regularly manufactured domestic service type of public utility current or gas can be delivered directly to the circuit at the primary transformers, because all the operating functions,

like the turning on and off of the current, and the measurement of it, can be taken care of perfectly satisfactorily by already approved apparatuses. A simple form of contract can then be made, with the public utility company, in which the city agrees to pay a certain rate per kilowatt-hour for the current measured by the watt-hour meters, installed at the primary transformer poles. The rate for this current should be established with full consideration of the characteristics of the load, as this load is one of practically unity load factor, during the time of operation, there being no fluctuation from the time of turning on until the time of turning off and its time of appearance and disappearance can be anticipated. However, as this load is not on during the daylight hours of the day, the load factor for the entire twenty-four hours is not so desirable, but the rate should take into consideration all sides of this question.

Again, a simple form of contract for the supply of gas to the units, or also including the maintenance of the service, could be made, the city making the initial investment and maintaining part or all of the system itself. At a suitable figure it might be advisable to contract with the gas utility to maintain the mantles and burners or other parts, on these units, at some equitable basis, which would assure supervisory and inspectional regulation of the quality of maintenance to the city. The gas units, including only the posts, fixtures, etc., would be the only part of the system to be installed by the city.

After considering all conditions, a contract was recommended to be made for, say, five years, with either or both utilities.

It was then recommended that a contract be entered into for the purchase, on the kilowatt-hour basis, of such electrical energy as may be required to operate the new street lighting system; and it was further recommended that contractual provision be made on an equitable basis for the continued operation of existing street lamps until these are superseded by lamps of the new system.

It was also recommended that a contract be entered into for the purchase of such amount of gas, and for the furnishing of gas burners, mantles and maintenance attention as may be required in connection with such gas lamps as are installed on the new system.

Legislative Enactments.—(*n*) Budgets, Ordinances, etc.—In

any city where a contract for the street lighting of the entire city is to be made, there will always be some legislative steps to be taken by the council or other bodies, in order to approve the contract, bond issues, budgets, or creation of departments or divisions of departments, in order that the city may perform its part of the contract. In the present case, besides the consummation of a contract on the above basis, the city would be called upon to pass enactments for the creation of a Division of Street Lighting of the Department of Public Works; and for a bond issue for the installation of the distribution system. It was also recommended that such legislative enactment be passed as will regulate and control the installation of street lamps by private individuals. Such last enactment should, in general, provide that only the types of posts and fixtures adopted as standard by the city be permitted to be installed, and only at locations shown in the street lighting atlas, and approved by the executive in charge of the division of street lighting.

CONCLUSION.

The new system proposed to be installed without delay will provide the city with approximately 8,821 units to be installed at the rate and in the locations cited in the recommendations and on the street lighting atlas, with recommendations for the future which will establish an ultimate system as near the ideal as is practicable. The atlas also shows how an installation could be made providing approximately 6,931 units, but appreciably improving the lighting of the streets.

It is earnestly believed that when the economic value of a system of street lighting is compared with other public works, such as schools, bridges, police force, fire department, etc., the price required to be paid for the protection of the life and limb of the entire citizenry; the protection of our wives and daughters from crime and annoyance; the protection of our property from burglary by supplementing the police force by adequately lighted streets; for the various conveniences to the public, secured by sufficient illumination on the streets, and the advertising and esthetic values of adequate street lighting to the city at large, and to the individuals—the cost of an adequate street lighting system will be found to be insignificant compared with the value received, and the expenditure well worth while.

DISCUSSION ON THE THREE PRECEDING PAPERS.

DR. CHARLES P. STEINMETZ: The first application of electric lighting was for outdoor illumination, and I believe the same can be said of gas lighting, a hundred years ago. Electric lighting, especially outdoor lighting, has become an important and serious problem, however, only in the last years by the development of a considerable number of available illuminants in the field of gas, incandescent and arc lighting, and the problem of street illumination then resolves itself into three factors, the source, the distribution, and the quality or color of the light. The efficiency of the light source is all important in street lighting where very large areas are to be illuminated, although even in this very low illumination densities must be accepted. Nevertheless, the expense of illumination is very considerable.

The enclosed alternating current arc had for a long time remained in universal use for street lighting until about ten years ago when it was replaced by the mazda type lamp as being more efficient, that is, giving much more light at less power consumption, and also giving a better quality of light, that is, white light. The flame carbon arc has never found much use in street lighting in this country. Incandescent lighting formerly came hardly into consideration, except as what I might call pilot lighting; that is, on country roads, etc., small incandescent lamps were used, not to light the roadway but to mark its location, the same as pilot lights mark the channel of the river. With the development of the gas-filled mazda lamp the incandescent lamp has reached an efficiency within the range of arc efficiency and become a formidable competitor of the arc lamp; this is true at least of the high current (20-ampere) lamp, which gives an efficiency of half a watt per candle of illumination. As a result, many illuminating engineers believe that the days of the arc for street lighting are almost over. However, this view is generally given up now, as we realize that while the incandescent lamp has found an extensive field in street lighting, the arc lamp will probably still retain its field in first class, high grade street illumination, in the form of the titanium arc, while the field of the incandescent

lamp will be that extensive region where the lower the cost of installation, and lower cost of operation predominates. Now we have to realize that we have not yet reached the limits of possible efficiency of the incandescent light, but we are fairly close thereto, as the efficiency is theoretically limited by the radiation law; while the efficiency of the arc has no theoretical limits. Since the coming of the incandescent lamp as a competitor of the arc we have, as seen by some, jumped by an increase of 60 per cent. to the efficiency of the luminous arc, while under laboratory conditions arc efficiency has reached far beyond anything in incandescent lighting, and it must be conceded that the arc light will always remain an illuminator. The incandescent lamp has greater flexibility, being available in units of thousands of candlepower down to units of 40 candlepower. The smaller units are less efficient than the big ones, but the falling off is nothing like what it is in the arc lamp. On the other hand, the incandescent lamp is yellow but the arc is white, so it is limited in quality, but the incandescent lamp almost always remains more sensitive to color than the arc. An arc lamp is not damaged by a 50 or 100 per cent. increase of current for a few minutes, while an incandescent naturally would be destroyed under those conditions. Therefore, the question of the momentary regulation of the currents supplied to the incandescent lamp has become a serious problem which did not exist in the days of the arc, and we see then from the papers which we have had before us, that the question of operation of a series of incandescent lamps has not yet settled down into standard lines, but there are different methods concerning which the experts disagree.

The second problem, that of distribution of illumination, is so vast that it is impossible here even to consider it. We have all condemned the old open arc with its high intrinsic brilliancy of the point source, its light distribution giving a very high lack of uniformity and in other days, as illuminating engineers, I believe we have all carefully studied the problem of giving perfect uniformity in the distribution of light on the street surface. In the last year we have experimentally received conclusive evidence that such a perfect uniformity of illumination density over the street surface would be extremely unsatisfactory, in many cases

worse than that of the old open arc, and that the problem of the distribution of light is a much more intricate and more difficult one than we have anticipated; that the question of directed and diffused light comes in; the direction of light in the silver effect which our chairman has studied so carefully; that the question of valuation of uniformity is a very important factor and that absolute uniformity is rather objectionable. Furthermore, the question of the color of light with respect to the predominant color of the illuminated objects, and a number of other features come into consideration in this problem.

The third problem, that of the quality and color of light has still less been studied; we know only in general. Now, in the case of low intensity light in the suburbs and on country roads, we have to consider the fact that the short wave light and the bluish light is more effective in very low intensities than the red wave of the yellow light, and therefore is a better illumination where we have to deal with, or be satisfied with low intensity, although the effect of surrounding objects is very essential in the satisfaction given by the light. In suburban lighting, the dominant colors are very largely the green foliage. Now the white light and still more slightly the bluish green, gives a much more satisfactory effect than the yellow where the red predominates. Yellow light is rather unsatisfactory where there is foliage and is therefore not very desirable in suburban lighting where the beauty of the street consists in its foliage, etc.

In high density light, ornamental lighting in the midst of cities, another problem arises in regard to the color, and that is, that in addition to street illumination there is a considerable amount of light coming from stores. This light is usually produced by small units, of incandescent light, that is, yellow light. Wherever, then, the street illumination is also yellow, the two illuminations blend into each other and destroys each other's effect; so that the effectiveness of window lighting and store lighting is rather reduced by street illumination of the same color, while inversely the varying amounts of light coming from the stores onto the street destroys the appearance of illumination by giving it a spotted effect. Here is where the main advantage of the white light lies in decorative lighting; it remains distinct from the store

lighting, and from the individual house lighting, as the two kinds do not interfere with each other.

All these questions have not been studied yet to a very great extent, and there is still a vast deal to do, so that while we are gradually getting into a systematic study of proper light, the illumination must still be judged by trying it and seeing how people are satisfied with it. Sometime in the future illuminating engineering may be advanced enough that it can decide before hand, from theoretical reasoning, what arrangement of lighting should be made and whether that will be the most satisfactory, as we can do now with designing machinery, etc., but we must realize that illuminating engineering is a vastly more difficult subject than machine designing, because it deals not only with physics but also with physiological and psychological effects. It is rather a broader subject. We also must realize that illuminating, as a separate branch of engineering, is not yet five years old.

Mr. H. Calvert: Following one of the thoughts of Dr. Steinmetz, I regret to see the use of the terms "long life" and "high efficiency" electrodes in a paper on the arc lamp. These two terms are only relative and do not mean anything. You recollect that when the metallized filament incandescent lamp was brought out, it was referred to as a "high efficiency" lamp. It had a higher efficiency than the lamp which preceded it, but it was very much lower than those which followed. This, I think, shows that it is an unhappy choice to use these two terms in referring to arc lamps, the development of which is still in its infancy.

Mr. S. G. Rhodes: As the chairman has indicated, we have listened to all phases of the street lighting problem. Any discussion, therefore, will have to do with the detail of some one of the papers. Having that in mind, and referring first to Mr. Rolinson's paper, first page, I desire to make it clear that, while constant potential lamps are in use in New York City, the fact must not be lost sight of that there are in addition some twenty-five thousand 100-candlepower series lamps and some five thousand 400 and 600-candlepower gas-filled lamps operating in straight series, that is, without a compensator, and operating as

well with compensators and also with the adjuster socket system to which he refers. On the sixth page, reference is made to the various forms of distribution possible with the series system, the adjuster system, compensator, etc. The author states that the compensator system is the best. I think that is a fair statement, if it is considered in connection with the fact that it is probably the best for overhead distribution. But consider, if you please, that when lamps of this character are served from underground cables that there is a capacity effect that must be reckoned with and the capacity effect may change and will change the current as delivered to the lamp by from maybe 10 to 15 or 20 per cent., and change it, not as a constant value, but change it in steps of one tenth of an ampere to two and three tenths. What effect that would have on the life of lamps will be noted when one considers that the chart has shown that less than 5 per cent. increase in the normal current rating of a lamp causes a decrease in the life of the lamp in excess of 30 per cent.

Reference is made on the tenth page to the necessity for reliable and adequate service, ventilation and protection from the elements. Ventilation is essential in the ordinary street lighting units for the type C lamp of 400 and 600 candlepower, but it is not quite so necessary, in fact it can be dispensed with, when a lamp is used in the lantern type of construction or with a large globe where radiation is probable. It is obvious that where the lamp is operated at its proper efficiency, it will be a better lamp.

Just a note on another very minor matter—but good service is made up of details; I refer to the question of globes and glassware, which is mentioned on the thirteenth page. It is stated there that the opalescent globe absorbs from 15 to 30 per cent. of light. The "cased" globe absorbs possibly 15 to 20 per cent., but hand in hand with the improvement in the gas-filled lamp has been the improvement in the enveloping glassware, and it is possible now to obtain from any of the reputable glass manufacturers a globe made of a single mixture with an absorption of about 12 per cent., and it is superior to the "cased" globe, that is, a globe made up of two or three walls of glass, in that it, unlike the cased globe, does not show the formation of the filament.

Mr. C. F. Lacombe: I read with a great deal of interest the

paper that Mr. Vaughn wrote in regard to the study of street lighting that he made in the city of Milwaukee and I regret to draw your attention to the fact that it seems that the author almost endangers his own plan by the great additional expense over standard systems of the complete installation he proposes, on account of the great elaboration of the system described. While one may not approve all the illumination details, there is no question that one should approve his description of the necessity of the study of street conditions for the determination of the required intensities classified as to streets, spacings of posts, types of units and the mapping and recording of the final installation. It is obvious from his paper that these studies have been made on the streets, which is a necessary condition, in my opinion.

In the very comprehensive study of this street lighting problem, a system of street lighting is described which could almost be termed luxurious in the elaboration of detail overcoming the difficulties of street lighting problems and reaching the utmost refinement of illumination. To follow the author to the point of recommending this illumination scheme with its consequent high investment and maintenance charges would be very difficult. While as interested as anyone in the advance of street lighting in cities in this country, I have found that one of the greatest obstacles to be overcome is the high cost of the distribution, street equipment and its maintenance. This practically controls the cost of street lamps, the energy costs being relatively the smaller factor. This cost represents the cost of the service of supplying and maintaining street illumination which is by far the most difficult part of the work, and as stated, the more expensive part, whether financed by the city or the company. The investment costs per lamp of the plan proposed which comprehends the entire lighting of Milwaukee would be much higher than that of any other installation of this scope in this country. This is due to the expensive elaboration of the underground system and of the equipment used to obtain the refinement of the illumination thought necessary. In an editorial written in March, 1914, after experiments in the fall of 1913 with gas-filled lamps, I stated that we needed a new lighting unit that would decrease our costs and give us more and cheaper illumination, and suggested

that this hope might be realized in the gas-filled tungsten lamp. Since then it has been used with just this effect and enables us with improved arc lamps to obtain the same illumination on our streets at a decreased cost or more illumination at about the same expense. One sees in the technical press, now, reports from many cities heralding large savings in this manner. If, however, we take this lamp and load it with the extreme investment costs necessary to refine street illumination to the point recommended, all the advantage of the lamp from the economical standpoint seems lost, when really the lamp could be utilized to improve the lighting with economy, if we did not attempt to refine it to a point where it almost vies with interior lighting as suggested in this paper. The plan as recommended contemplates a system very largely of underground construction throughout the entire city including the suburbs. This involves almost prohibitive expense in suburban lighting and loses any benefit from the present overhead construction available. No public service commission in this country insists on suburban service or extensions of service of this character for the reason that they realize the business obtainable would not justify the investment.

The plan also involves the most elaborate precautions to eliminate glare. Glare is not desirable, but a system can be designed at much less expense than that recommended, which, while it will not eliminate all glare, will reduce it to a point where it is practically unobjectionable. In the recommendations made, I should judge the cost of removing glare, beyond the usual precautions now practised, in the 30-foot post units is $17.50 per post. While the number of these posts is not given, it is presumed there are at least 1,000 which, as you will note, makes a considerable investment which may be avoided. Added to this are the similar lantern and refractors for all the rest of the lamps at an extra expense of at least $5 each for about 7,500 lamps. In the small lamps again the redirection and diffusion of the rays usually loses so much of the illuminating power that in my opinion it is wasteful to so treat such lamps. The glare can be mitigated in less expensive ways.

The cost of the equipment proposed for the extreme safety is also expensive. This would seem unnecessary except possibly in the most congested districts. In the suburban

districts overhead wiring and bracket lamp construction would certainly be much cheaper than that proposed and as far as the public is concerned, if well constructed, would be safe. It would appear therefore that the imposed requirements, first of a practically complete underground distribution system, second, the costs imposed to eliminate glare, third, the extreme safety requirements in the suburban districts, taken together will add a very large sum to the cost of the system. In these times cities, like individuals, are practicing rigid economy and a city would not be justified in making an investment of this kind unless its financial condition was such that it could afford all the luxuries it desired.

One more point only. While it is unfortunate in technical discussions to interpolate the question of municipal ownership and in consequence I would not discuss it, my long association with the City of New York might by silence be construed as agreeing with this recommendation of the report. I do not so agree as a direct result of my municipal experience. My experience has taught me that at this time under our political system it is impossible to insure the continuous and consistent business and engineering control necessary to the continual success of electric service rendered by a municipality. The exceptions to this tend strongly to prove the rule. The matter was carefully investigated in New York by boards of engineers and it was found that the better course was to pay a fair and reasonable price for service and let the lighting companies defray the many expenses of changes of equipment and maintenance due to the improvements of the art, the life of the various parts of the equipment and the distribution service, the service rendered to be carefully inspected, measured and watched by an inspection bureau which enforced the contract requirements, audited the bills and imposed reasonable outage penalties. With such a bureau and with the supervision as to rates and the expert aid given by a railroad commission of the highest standing, it would seem entirely unnecessary for a Wisconsin city to try the very doubtful experiment of municipal ownership even in part, with its inevitable division of responsibility, particularly where it assumes the hardest part of the service requiring the most care and expense, and leaves to the utility by far the easiest part.

Mr. G. W. Roosa: Mr. Rhodes raised the point of proper ventilation of the type C mazda lamp. I recall an installation which includes approximately three hundred fifty, 250 candle-power, 6.6 ampere series lamps operated on ornamental posts with the tips in an upward position and enclosed in ball globes of 16 inches in diameter with no ventilation opening in the top, and with a very small ventilation opening in the bottom, in the globe holder. The life secured from these lamps is about 1500 to 1800 hours for the whole installation.

Mention has been made of the adjuster socket system. I want to call attention to an installation which uses the adjuster socket system in ornamental poles and the coils, instead of being mounted directly adjacent to the socket, are put in weather-proof metallic cases filled with gum and located in the bottom of the posts. This installation proves to be a very practical and successful one.

A point was brought up concerning the sharp contrast from the use of clear glass globes on arc lamps, the contrast showing a definite line on the buildings. I found that this can be overcome with the use of a globe with the lower portion clear and the upper portion of a diffusing character, and the line between the upper portion or diffusing portion, and the clear portion, does not have to be in the horizontal plane of the point of the arc; it can be higher, thus allowing fairly good illumination further up on the building. This will give one advantage—there will still be the same illumination below that was obtained with the ordinary clear globe, and added to that a certain reflection from the upper part of the globe.

Mr. J. R. Cravath: At the present time, with existing installations, it is frequently possible to greatly improve conditions by the use of incandescent lamps, at a very small expense for the change, because they fit in with existing street lighting apparatus much better than the luminous arc. The street lighting art has been advancing very rapidly in the past ten years and may advance even more rapidly in the next ten. In view of that fact, it is frequently desirable to recommend changes of this kind which involve a minimum investment for the present and which also permit the greatest flexibility for possible future changes.

The question of the ownership of apparatus and lines has been handled by Mr. Vaughn in a way not generally used in this country at the present time, but after all not very different from present methods of handling the purchase of electrical energy for private use. For example, the owners of this hotel would not think of contracting for electricity on the flat rate basis from the electric light company, the electric light company to own the wires. In a street lighting installation, if the city owns the lamps and the distribution system, pertaining directly to street lighting, it makes far simpler any changes to be made to keep abreast of new developments in street lighting. I mean that it is simpler from the political standpoint.

I think it would be very interesting if Mr. Vaughn would give us a few figures on what this new system for Milwaukee is going to cost, as it does not seem evident to me that the system is likely to be so tremendously expensive as Mr. Lacombe maintains.

Mr. S. C. Rogers (In reply): The terms "long life" and "high efficiency" have been used merely to distinguish between the two different commercial electrode mixtures.

In calling attention to the sharp line of demarcation between light and shadow, as is sometimes seen, we did not refer necessarily to a clear globe equipment, as such effects may be produced by any device which suppresses the upward light. We did not discuss a method of obviating this difficulty, since we referred only to the results as obtained by any type of distribution which directs light in a downward direction only and none upward.

Mr. Ward Harrison: Mr. Vaughn has impressed us all with the fact that a revolution in the method of street lighting is likely to take place within the near future. At the same time he pointed out that only in rare instances does the illuminating engineer have an opportunity to plan a complete system for a city without interference from the restrictions due to local conditions and previous equipment, though the latter is often very inadequate and out of date.

The incandescent lamp adapts itself readily to the old systems of distribution and often to the old electric appliances so that at a very low investment a great immediate improvement can be effected, even in the many instances where the engineer is handicapped by lack of funds. In fact, the investment is so low that

usually, even if the whole system were reconstructed at the end of twelve months service, neither the city nor the lighting company would have sustained a loss through changing the lighting to the more modern incandescent equipment. Furthermore, while improvements may be developed in all illuminants, these improvements are often of such nature as to require scrapping of the old equipment and purchase of new in order to utilize the advance. However, improvements in the incandescent lamp resulting in increased efficiency are automatically incorporated in the system almost at once, for renewals take place from two to three times per year in this type.

Fig. A illustrates one of the common types of fixtures used in replacing obsolete equipment with the series incandescent lamps of from 250 to 1000 candlepower. The particular fixture shown in the cut accommodates a straight series or multiple socket and does not provide for the use of a compensator. As an alternative to the use of a compensator fixture to take advantage of the higher efficiency of the 15 and 20-ampere lamps, middle west cities have found a two-coil pole-mounted transformer in many cases to be preferred, for it not only steps up the line current to the value required for the lamps but at the same time it insulates each unit from the main series circuit. Careful reports from many towns have shown that at least three fourths of the trouble on series circuits, where the units are center suspended, occurs between the posts and the lamps. This large proportion of circuit trouble is eliminated by the pole-mounted two-coil transformer, for if one unit is accidentally torn down or a wire becomes disconnected, or if a ground occurs, the remainder of the system is unaffected.

The characteristic distribution of light from a 400 candlepower lamp fitted with a refractor fixture, such as is shown in Fig. A, is illustrated by Fig. B. As Mr. Rolinson has explained, by the use of a refractor the maximum intensity of the lamp is more than doubled at the angles considered useful in street lighting. Furthermore, through adjustment of the relative position of the lamp and refractor, it is possible to vary the angle of maximum candlepower. Examination of installations in Cleveland has led to the conclusion that though the center of the block is better lighted where the maximum is had at the 80° angle, the entire

effect is superior when the refractor equipment is adjusted to produce the maximum at 75° as in the curve shown. The glare felt in looking down the street is very much reduced by the directing of light at the lower angle. Also, while in the curve shown practically all the light is incident upon the street surface, if the maximum should be produced at a higher angle, as for example, 80°, 20 or 30 per cent. of the light would be emitted at or above the horizontal and would not be effective in lighting the street surface.

As an instance of the advantage that may be gained by replacing obsolete lamps with incandescent equipment of the type referred to: a standard circuit consisting of 50 7.5-ampere alternating current enclosed arc lamps requiring approximately 490 watts each, can be replaced by 100 600-candlepower lamps which take 300 watts each (including transformer loss) without increasing the tub transformer or central station capacity. Half of this increase in the number of units per circuit is due to the reduced wattage per lamp; the remainder is secured through the high power factor of the incandescent system which permits a larger load in actual wattage with the same station apparatus.

If the candlepower only which is effective in illuminating the center of the block be considered, in the example given, the light is increased in a ratio of at least 8:1. On the basis of mean lower hemispherical candlepower the effective light is four times greater. In view of the fact that the highest intensity from the arc is directed to a narrow zone on the street about the lamp, the improvement in illumination is more nearly of the order of the 8:1 than the 4:1 ratio.

The principle of the refractor has been applied recently also to units for high intensity business street lighting. Fig. C illustrates the post and lantern which is being used in Cleveland's new ornamental street lighting system. The lantern contains an incandescent lamp of 1,000 to 1,500 candlepower which is supplied from a two-coil transformer placed in a manhole near the base of the post, in the manner referred to in Mr. Rolinson's paper. The engineering features of the lantern were planned by the engineering department of the National Lamp Works; from the artistic standpoint the post as well as the lantern was designed by the city architect of Cleveland.

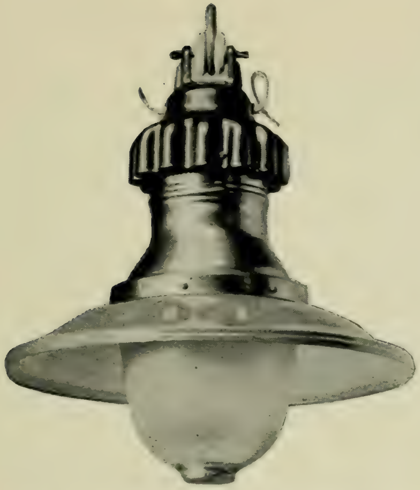


Fig. A.—Refractor fixture for series lamps.

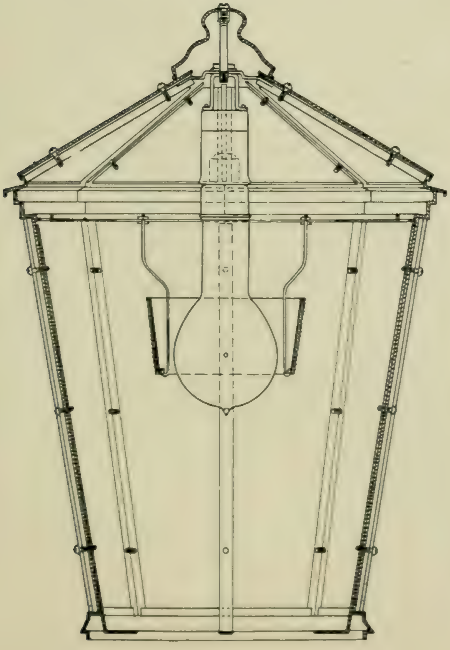


Fig. D.—Details of Cleveland lantern.

Fig. C.—Cleveland ornamental
lamp standard.

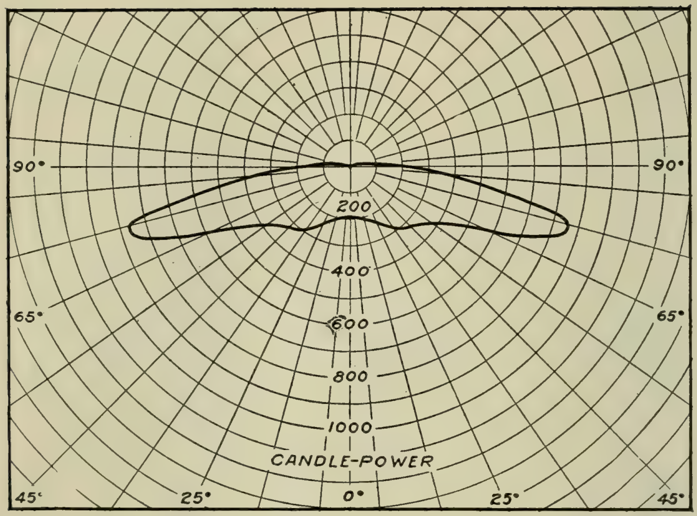


Fig. B.—Typical distribution curve of 400 candlepower lamp with refractor unit.

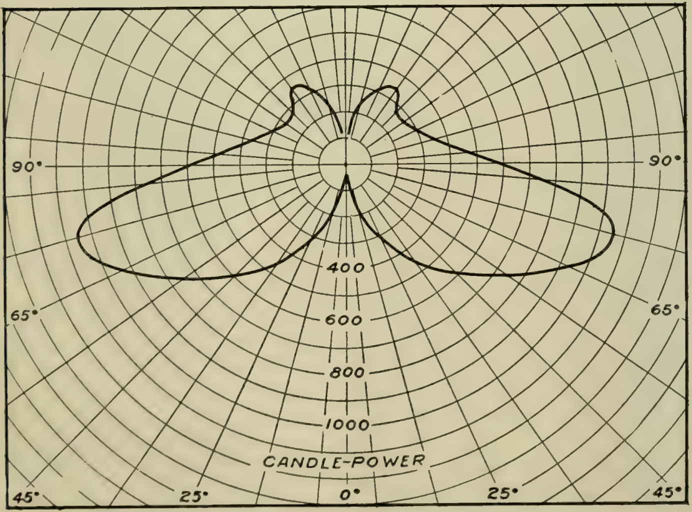


Fig. F.—Distribution curve of Cleveland lantern with 1,000 candlepower lamp.

The interior arrangement of the lantern is shown in the diagram of Fig. D. The band of prismatic glassware which surrounds the lamp bulb intercepts the light rays which are ordinarily sent out in the zone from 10° below the horizontal to about 50° above and redirects them at the lower angles which illuminate the street surface. The effect of the refractor is evident from the distribution curve of the lantern shown in Fig. E. A high intensity is secured in the angles from 60 to 75° and there is less light in the zone near the horizontal where high candlepower results in glare. A low candlepower is directed toward the second story line of the buildings where it would interfere with the sign lighting, but a higher intensity is supplied in the zone from 135 to 165° which is important in bringing out the facades of the buildings.

The wavy surface of the glass used in the lantern panels does not collect dirt as does a roughened surface and at the same time it presents a more sparkling appearance than the latter. The glass contains a slight amount of opal which, combined with the irregular surface, furnishes a degree of light diffusion sufficient for a good appearance without nullifying the redirecting effect of the prismatic refractor.

More than 600 of these units are being put in service and it is planned to double that number within a short time after the first installation has been completed and its cost carefully ascertained. The choice of the equipment was made after a careful investigation of the available systems of illumination which included comparisons under actual service conditions. Fifty posts were erected on an important part of Euclid Avenue and each manufacturer who wished to exhibit was permitted to place his lamps upon these posts. The choice of the incandescent lantern unit system was reached after the lighting effect and operating cost of the different trial installations had been compared over a period of several months.

Mr. F. A. Vaughn: I do not think that I will be generally misunderstood as wishing to give the idea that the specific recommendations made for the City of Milwaukee are necessarily general recommendations. They are the result of the study of this specific problem, and they of course take into consideration the

local conditions in every possible way. Relative to the recommendation, for instance, regarding city ownership of the distribution system—while I think it is rather out of order to discuss it in this sort of a meeting, and I had no intention of doing so except for Mr. Lacombe's remarks—I simply wish to say that such a plan is only one available means of overcoming some of the difficulties involved in the older type of the per-lamp-per-year basis of contract. There may be others. This is the one believed to best suit the local conditions at Milwaukee.

In regard to the cost of the system, since Mr. Cravath has asked for it or suggested that I might give it, I can give briefly one or two figures which perhaps will dispel some of the pessimistic apprehensions of Mr. Lacombe, because this matter of course has been—and must be—in planning any system—taken into consideration. The proposed system must be one that can be afforded, and that idea has been uppermost in the engineer's mind in planning this one. For instance, I wish to say that a tabulation of the per-capita cost in the cities of this country ranging from 600,000 down to about 300,000—that is, the Milwaukee class—will show that Milwaukee is now paying the least per capita of any of those cities, namely, 54¢, while the average is 84¢; that when the proposed system is installed as contemplated, by what we call the second group, or approximately 8,821 units, Milwaukee will be asked to pay 77¢ per capita,—that is 10¢ below the average of its sister cities. The cities in that class, however, run well over a dollar, several of them, and a majority run in the region of 80¢ to $1.00. Regarding the actual cost of the system as compared, for instance, with a system which was proposed by the local utility and discussed and reported upon in a report by the Railroad Commission of Wisconsin, and which would have been adopted in Milwaukee a year ago if one more vote in the Common Council had been available,—the cost of that system as then proposed, namely, practically a straight magnetite system, with some incandescent lamps, was $880,261. By the financing of the distribution system by the city, in this particular case, whereby the annual investment and depreciation charge of $107,192 then allowed by the Railroad Commission is assumed by the city, with its low interest charge and its advantageous position due to its ability to amortize the equipment over its entire

physical life,—a system costing $1,030,000 can be afforded on an equal annual investment and depreciation cost. The city also avoids the possibility of having to pay depreciation more than once when the contract is renewed from time to time.

If the first choice, approximately 6,931 unit system, is decided upon, it will cost $1,169,814. The second group system, which involves approximately 8,821 units, will cost in Milwaukee something like $1,329,896 instead of $880,000 for the system as proposed a year or more ago. This is a rise in the cost per capita from the 54¢ at present paid to 77¢—10¢ below the average referred to above. Ninety-five cents per capita per year may be taken as the present street lighting expenditure level for progressive cities of Milwaukee's size, as established by the practise of 75 per cent. of the cities of this size.

If the system can be assumed to have an average life of twenty years, which seems reasonable for a distribution system only, involving no operating equipment, and consisting practically entirely of ornamental, reinforced concrete posts; renewable incandescent lamps; underground steel taped cable, protected against electrolysis; low voltage on all parts of the system, especially low at posts and exposed parts,—then the foregoing allowance of $107,192 for annual investment charge, depreciation and $11,361 for lost taxes will even carry the system recommended in the second group. Now these costs, considering the advantages in the system involved, it is believed are not extravagant, but on the other hand are a small price to pay for the civic benefits received. Nine per cent. of the annual street lighting cost goes to provide attractiveness of appearance rather than to provide any utilitarian quality of service. It is believed by the engineers that 9 per cent. is a very modest proportion to expend for considerations of appearance.

The Common Council has voted enough money to install approximately 40 square blocks, or 8 miles of street, for the demonstration of this system and contracts for its installation have been signed. It will be in operation sometime after Christmas and at that time the City will be very glad to have any one inspect it, and the actual costs will then be available.

Mr. Ray Palmer (Communicated): I am most interested in the factors of economic and efficient light generation and distri-

bution, including initial costs of installation; also operation and maintenance of equipment. By economic is meant the most practical system for the local taxpayer, giving to the citizens of the community a high degree of service and protection by utilizing all local conditions and factors which will be economical to the taxpayer in the solution of his problem.

Few cities can afford to pay large sums of money for the esthetic value of lighting. Some expenditure for this factor, however, should always be considered in the solution of public lighting problems. It is my belief that the illuminating engineer and the engineering fraternity as a whole should work as a unit as far as possible in standardizing lighting equipment, and the installations themselves. There should not be special glassware including a special refractor for each city, the relative spacing and height of similar candlepower lamps should not be materially different, nor should one distribution system be very differently installed, maintained or operated than every other system, unless there are economic or practical features resulting which will benefit the citizen and taxpayer.

AN "AVERAGE EYE" FOR HETEROCHROMATIC PHOTOMETRY, AND A COMPARISON OF A FLICKER AND AN EQUALITY-OF-BRIGHTNESS PHOTOMETER.*

BY E. C. CRITTENDEN AND F. K. RICHTMYER.

Synopsis: The comparison of lights of different colors is supposed to be based on an "average normal eye." This paper records an attempt to approximate the results of such an eye with typical color differences by using a large number of observers. In particular, results obtained by a flicker photometer and by an equality-of-brightness photometer, with different degrees of color difference, are compared. In terms of the Ives-Kingsbury test solutions, for which the proposed normal ratio of transmissions (with a 4 wpc. carbon lamp) is 1.00, the average of 114 observers gives a ratio of 0.99. By using these test solutions results obtained on the flicker photometer by a small number of observers can be corrected so as to give normal values with a high degree of accuracy. On the average, equality-of-brightness measurements also vary in proportion to the test ratio, but erratic variations often overshadow these systematic differences. For sources having relatively high intensity in the blue, flicker values tend to fall below those obtained on the usual standard photometers, but the difference is comparable in magnitude with the uncertainty of the latter values.

Contents:

I. INTRODUCTION.

The work to be reported in this paper was undertaken in connection with the Committee on Research of the Illuminating Engineering Society. The reports of that committee[1] for 1914 give

* A paper read at the mid-winter convention of the Illuminating Engineering Society, New York, February 10, 11, 1916.

The Illuminating Engineering Society is not responsible for opinions or statements advanced by contributors.

[1] TRANS. I. E. S., vol. IX, pp. 307, 333, 345, 358, 505, 1914.

a general survey of photometric problems on which investigation is especially desirable. Following this general review, it was felt that the new committee appointed for 1915 might most effectively stimulate investigation by choosing a particular field and arranging for experimental work in it. The field chosen was that of heterochromatic photometry. In order to accomplish something definite within the time available for the investigation it appeared desirable to confine the work within rather narrow limits, and it was decided to give attention primarily to the question of the methods to be used in actual photometric comparisons involving a color difference, and to such phases of this question as could be studied in a single laboratory.

As a solution for the whole problem of photometry with a color-difference the use of a flicker photometer under certain specified conditions has been proposed, in particular by Dr. H. E. Ives.[2] To strengthen the position of the flicker instrument there has been developed also a complete scheme[3] for the choice of normal groups of observers, including the establishment of an "average eye." This proposed systematization of heterochromatic measurements appeared so definite and practical as to deserve a thorough trial.

The present work was therefore planned to show the difference to be expected between individuals and to include readings by a large number of observers so as to establish average or normal values for various measurements involving color differences. In general similar measurements were to be made on a flicker photometer and on an equality-of-brightness photometer in order to establish the relation between results obtained by the two methods and the relative certainty of measurements made by the two types of instruments.

The experimental data to be presented were obtained in the laboratories of the Bureau of Standards during the summer of 1915. Besides extensive preliminary tests, the data obtained include (1) readings by 115 observers on the Ives-Kingsbury test solutions for choice of observers, (2) measurements by the same observers on blue glasses presenting a color difference equiva-

[2] *Phil. Mag.* (6) 24, p. 852, 1912; TRANS. I. E. S., vol. X, p. 317, 1915.

[3] Ives & Kingsbury, TRANS. I. E. S., vol. X, p. 203, 1915.

lent to that involved in comparing carbon lamps with vacuum tungsten lamps, (3) a repetition of the above measurements by a selected group of observers, (4) sets on a blue solution corresponding to the color difference between a carbon lamp and a gas-filled tungsten lamp, (5) a direct comparison of lamps operated at the color of the pentane lamp flame with others run at 4 watts per candle, and (6) the calibration of a blue solution and measurements with it on lamps at various efficiencies.

With the exception of the solution used in testing observers, it may be noted that the work has dealt only with color differences of the type given by two incandescent bodies at different temperatures, such as two lamps operated at different efficiencies. Lights showing this type of color difference are of course much more easily compared than those showing a more nearly "saturated" hue, but the difficulties are sufficient to impair very seriously the accuracy of many practical photometric measurements required at the present day. It is highly desirable that a method of comparing the intensities of lights of different colors which can be used for all types of color difference shall be agreed upon, but at present the field in which there is most urgent need of a high degree of accuracy in such comparisons is the rating of incandescent lamps; in the present investigation it has appeared desirable to make those tests which would have the most direct bearing upon the practical application of the instruments and methods involved.

II. APPARATUS.

Two standard photometer bars were arranged as nearly as possible alike, on one of which a flicker photometer was used and on the other a Lummer-Brodhun photometer. In each case the photometer head was stationary and was illuminated on the left by a stationary lamp placed at such a distance as to give an effective brightness of about 2.5 millilamberts after allowing for losses in the apparatus.[4] A similar lamp on a carriage at the right

[4] There has been some confusion as to the exact field brightness used in various investigations, partly because of the lack of a convenient nomenclature. In making the measurements recorded in this paper the effective brightness used was 2.5 millilamberts, that is, the brightness produced by an illumination of 25 meter-candles on a perfectly diffusing and completely reflecting surface. The numerical values for the test ratios given, however, were reduced to the basis of an illumination of 25 meter-candles on a surface having a reflecting power of about 90 per cent. Since a specification of the absolute brightness is preferable, it would be better to use 2.5 millilamberts as the standard brightness. To change to this condition, all values of test ratios as given in this paper should be reduced by 0.003.

was moved by turning a wheel beneath the photometer, and the cells and glasses referred to later were inserted on this side of the photometer so that a constant illumination was maintained. Settings of the movable lamp were printed on a record sheet and were measured from reference lines on the sheet, proper allowance being made for the optical thickness of the cells. This method of recording settings is much quicker than reading from the bar; it also has the advantage of giving a permanent record free from the errors which are likely to be made in transcribing numerical readings. The mean of the groups of points can be located very quickly with a sufficient degree of accuracy. In these tests each observer was asked to keep a tally of the settings, which required taking the hand from the wheel which moved the lamp, as well as turning away from the photometer.

The lamps used have double hairpin carbon filaments in one plane, and were operated at a voltage which made them match the color of the Bureau's 4 wpc. standards. For the distances at which the lamps were used, the illumination given follows the inverse square law with a sufficient degree of exactness so that no corrections were necessary. The voltage was controlled by potentiometers.

The flicker photometer used was a standard Lummer-Brodhun head with the rotating prism attachment described by E. F. Kingsbury.[5] The particular instrument used was very kindly loaned by Mr. Kingsbury. The photometer head was modified by removing the original prisms and putting in a pair of which one has two quadrants cut away so as to make the duration of exposure to each light the same (See Fig. 1A). In the flicker attachment as originally made the focal plane of the eyepiece fell considerably beyond the comparison prisms. By inserting a collar to extend the telescope the instrument could be made to focus on the face of the prisms, this arrangement being intended for use in making equality-of-brightness settings with the flicker prism at rest. A considerable number of trials indicated that for most observers this arrangement was decidedly better for flicker settings. It was consequently used throughout the tests. Without a very good photometric field this could not be done, since any imperfections in the field would cause flicker, but the prism

[5] *Jour. Franklin Institute*, 180, p. 215, (August), 1915.

used was sufficiently good so that with a color and intensity match there was practically no flicker in the field even at low speeds.

A tachometer was attached to the flicker mechanism and the speed was controlled by a rheostat in series with the motor. It was expected that each observer would have to choose a suitable speed for each color difference measured, but extensive trials with a number of observers showed that, over a limited range, change of speed had very little effect either on precision of setting or on the mean result. It was finally decided to adopt a moderate speed (12 light cycles per second) for all observers and all settings. Observers were then directed to set for a minimum of

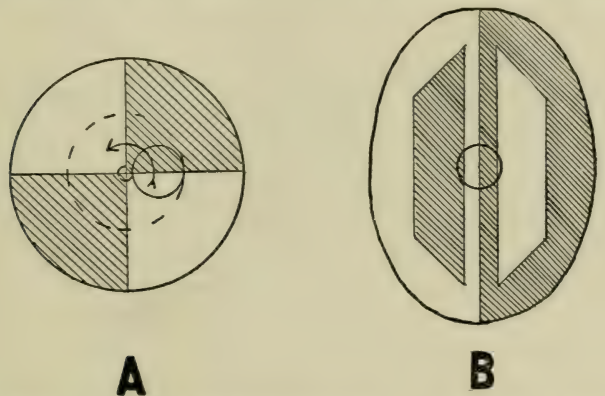


Fig. 1.—A. Type of field used in the flicker photometer. The small circle which one observes travels over the field as indicated. B. Lummer-Brodhun field in the equality-of-brightness measurements. (Contrast type, not indicated by sketch.) The circle shows the part used for the small field, the remainder being covered by an illuminated diaphram.

flicker. Although this speed was rather low for settings on the yellow solution and high for those with color match, few observers found serious difficulty in making definite settings. The constant speed was adhered to partly because in the preliminary measurements there had been indications of slight changes of results when speeds much higher or much lower were used, particularly with the yellow solution.

On the second photometer bar measurements were made under two conditions, (1) with the standard Lummer-Brodhun contrast field, (2) with an illuminated diaphram which limited the

field to about 2° as in the flicker instrument (see Fig. 1B). In the case of the contrast field, however, all observers were asked to make their settings by the middle strips, disregarding the contrast trapezoids. The small field was used because it gave equality-of-brightness measurements under conditions closely similar to those used with the flicker instrument. It was also thought that by limiting the field so as to use only a fairly homogeneous part of the retina variations in judgment might be reduced and settings more truly characteristic of the observer's eye might be made.

Each photometer head was provided with holders for absorption glasses, as well as holders for absorption cells, specially constructed to prevent any diffusion of stray light into the photometric field.

Three pairs of 1-centimeter cells were provided. These were constructed practically like those described by Ives and Kingsbury,[6] with removable sides of colorless optical glass. A small modification which was found to facilitate secure sealing of the sides was made by beveling slightly each edge of the cell blocks, thus making a groove to be filled by the paraffin seal. Although the sides were made of polished plate glass it was found that there were appreciable differences between the transmission of different plates. Repolishing of the plates which was necessary after using some solutions also changed the transmissions perceptibly. The differences and the changes mentioned were less than 1 per cent., but were not negligible for precise work. So far as color is concerned the glass used was satisfactory. It had been obtained for other work requiring very clear glass and its applicability for the present purpose was tested directly by measuring its transmission for the two extreme colors of light to be used, that is, the light transmitted by the two test solutions. Its transmission for the two was the same within 0.2 per cent.

Considerable time was given to experiments with the cells to determine how closely conditions could be reproduced. In brief it may be said that results can be rather easily reproduced to within 1 per cent. with them, but if an accuracy greater than ½ per cent. is desired extreme care is necessary. In any case

[6] TRANS. I. E. S., vol. IX, p. 795, 1914.

thorough cleaning is essential, and it is desirable to compare the cells with each other after each cleaning.

The paraffin used for sealing the cells is somewhat difficult to remove completely from the plates, and a supply of hot, running water is almost a necessity for thorough cleansing. Xylol also is a convenient solvent of paraffin and is especially useful when the supply of hot water is not plentiful.

Cells should be filled well up to the neck, for if a meniscus of considerable size is left an appreciable amount of light may be reflected from it into the field.

III. MEASUREMENTS ON THE IVES-KINGSBURY SOLUTIONS FOR SELECTION OF OBSERVERS.

The method of selecting observers to which reference has been made[7] is based on determinations of the relative transmission of two solutions, one reddish-yellow, the other blue-green. These are solutions, in water, of potassium bichromate and of copper sulphate, containing respectively 72 grams and 53 grams of the salt per liter of solution. While not definitely specified in the original proposal it has been assumed that the solution is to be made up at 20° C. and that by copper sulphate is meant the crystals $CuSO_4 + 5H_2O$.

When measured at 20° C. by the "average eye" with a flicker photometer conforming to specifications previously mentioned 1-centimeter layers of these two solutions were intended to have equal transmissions for the light of a carbon lamp of the standard 4-watt-per-candle color. The average eye thus defined was originally established by measurements made by 61 observers on the transmission of a green solution;[8] the two solutions above described were worked out later on the basis of measurements made by selected groups of observers. It is not at all clear, *a priori*, that an average established by comparing the middle of the spectrum with the whole spectrum can be legitimately thus transferred by a few observers to the basis of a comparison of the two ends of the spectrum; for instance, it is conceivable that an observer might be abnormally sensitive or non-sensitive in the

[7] TRANS. I. E. S., vol. X, pp. 203-206, 1915.

[8] Ives & Kingsbury, *Phys. Rev.* (2) 5, p. 230, 1915.

middle of the spectrum and yet appear normal in the comparison of the two halves of the spectrum, or he might be normal according to the first test and not so by the second. In fact it would appear that tests of both kinds should be included in choosing observers for measurements of illuminants which show marked selectivity in the visible spectrum. Ives and Kingsbury state, however, that groups of observers selected by one criterion were found to satisfy the other. For the types of color difference with which the present investigation has been most directly concerned the two-solution test appeared most significant, besides being more convenient than the earlier one. This method alone has therefore been used for testing observers, and the characteristics of a given observer will be supposed to be represented by the ratio of the transmission of the yellow solution to that of the blue solution, as measured by that observer, although it is recognized that this ratio is more strictly an index of the observer's sensitiveness to lights in which different proportions are contributed by the two ends of the spectrum.

Preliminary Measurements on Solutions.—The standard temperature for the solutions is 20° C. The greater part of the present work was done at temperatures ranging from 25° to 30° and consequently it was necessary to determine the temperature coefficients of the transmission of the test solutions. Over the range considered, the variation with temperature was found to be practical linear. The transmission of the potassium bichromate solution decreased nearly 0.2 per cent. per degree rise of temperature, while that of the copper sulphate solution decreased about half as much. The differential correction to be applied to the ratio of the two transmissions was therefore practically 0.1 per cent. per degree centigrade, the observed ratio (Y/B) being too small when the temperature was above 20°.

Other conditions which affect the value of the ratio obtained are the color of the light for which the transmissions are measured and the brightness of the photometric field. The color is supposed to be that of the standard 4-watt-per-candle carbon lamp and the brightness 2.5 millilamberts, equivalent to an illumination of 25 meter-candles on a perfect white surface after allowing for losses in the photometer. In the particular instruments

used these losses aggregated nearly 50 per cent., so that the actual illumination necessary was about 50 meter-candles.

Since the variation of results arising from changes in the efficiency of the lamp or in the illumination used is small, no very precise determination of the effects of such changes has been made. Some measurements were made, however, with a lamp operated at 3.1 and at 5.0 watts per candle, and with effective illuminations of approximately 10 and 50 meter-candles. In accordance with the reversed Purkinje phenomenon shown by the flicker photometer[9] it was found that the ratio of transmissions (yellow ÷ blue) was smaller at the higher illuminations. At 50 mc. the average of three observers gave a ratio slightly over 1 per cent. lower than the normal, while at 10 mc. the ratio was 2 per cent. higher than normal. A rise in the efficiency of the lamp naturally causes a decrease in the observed ratio, but the variation is so small that the effect of any error likely to occur in the rating of the lamp would be entirely negligible. Running the lamp at 3.1 wpc., or at 5 wpc., instead of 4, causes a departure from the normal ratio of only 1 to 2 per cent. It may be well to record that the fundamental 4 wpc. carbon standards have oval-anchored filaments and since their average reduction factor is 0.825 the standard efficiency is 4.85 watts per spherical candle or 2.6 lumens per watt. The color of the light is practically the same as that given by a vacuum tungsten lamp at 3.1 wpc. or 3.2 lumens per watt.

The composition of the test solutions is such that there is no reason to expect any difficulty in reproducing them or any change with time. Cells used for several months during the investigation showed no appreciable change in transmission.

Measurements to Establish a Normal Characteristic Ratio.—In order to obtain an independent check on the average eye as defined by the test solutions and to test the characteristics of observers to be used in later measurements, and at the same time to establish the relation between the characteristic ratio and some measurement met with in practical work a series of measurements was made by 115 observers. On each photometer this

[8] See footnote 4.

[9] Ives, TRANS, I. E. S., vol. V, 717, 1910; *Phil. Mag.* (6) 24, p. 170, 1912.

series consisted of 8 sets of 10 readings each; on the flicker photometer sets were made on the two lamps at color match, and on the same lamps with a blue glass screen and with cells containing the two test solutions interposed in succession on one side of the photometer head. The four sets were immediately repeated in different order. The data given therefore are the mean results of 20 settings of the photometer on each condition.

The original plans were to include a similar series of measurements on the equality-of-brightness photometer, but with it only the most experienced observers could make any definite settings on the test solutions, and even they varied so greatly from day to day that the results were quite useless as an indication of the observer's color characteristics. For instance, ratios determined on one day by the mean of several hundred settings could not be repeated within 10 per cent. on the next day, although the same observers could reproduce their ratios day after day on the flicker photometer with an average deviation of less than 1 per cent., only 20 settings being made on each solution. Consequently the equality measurements were made only on the smaller color differences, such as that presented by the blue glass screen for which the results are given in the next section. One observer was unable even then to make settings definite enough to be used, and his results are consequently not included in the following data although his flicker settings were good.

With very few exceptions, the observers included in these measurements are men who have had some years of experience in physical or chemical observations, and nearly 30 of them have had considerable recent practise in some sort of photometric measurements. The distribution of 114 observers with respect to characteristic ratio (Y ÷ B) is shown in Fig. 2, where the ordinates represent the number of individuals falling within a range of 2 per cent.; for example, between 0.890 and 0.909, inclusive, there are 4 observers. Such frequency curves must be used with caution since their shape can often be greatly changed by grouping in different ways. In this case the number of individuals must be considerably increased before it can be told with certainty whether the unsymmetrical shape of the curve is accidental, but there is a marked indication of the existence of a fairly definite

type of eye which gives systematically high ratios in the neighborhood of 1.10 to 1.12. The solid black rectangles represent three men who were found to be definitely color blind in a test made by Mr. I. G. Priest with Nagel test cards. Some others in this group are known to have peculiarities in their color perception although they are able to pass color vision tests.

The arithmetical average of the 114 ratios is 0.990. If the three observers classed as color-blind are omitted the average is 0.986, but actually the line between normal and abnormal color vision is very difficult to draw; moreover, the relation between

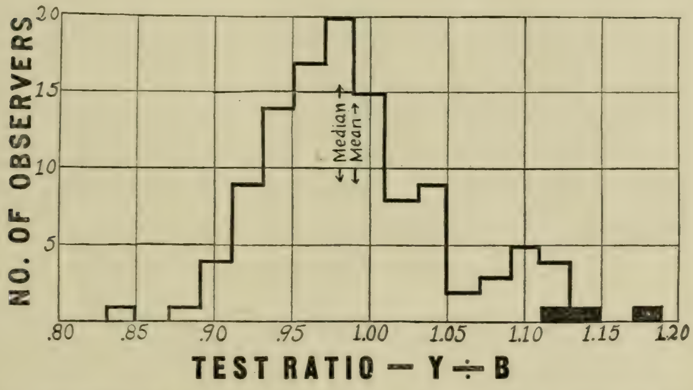


Fig. 2.—Distribution of 114 observers with respect to characteristic ratio (ratio of trans mission of yellow test solution to that of the blue solution). The ordinates show the number of observers falling in a range of 0.02 in ratio. The black rectangles "color blind" observers.

color and luminosity is not very definite, and in making up an average luminosity scale there is little justification for ignoring that percentage of the people who are color-blind. On the other hand, taking an average may give undue weight to the abnormal observers, and there is some advantage in taking instead of the average the median value, that is, a value such that there are equal numbers of observers above and below it. In this case the median for the 114 ratios is 0.980, and the effect of omitting the three extreme observers mentioned is only to make the median fall between 0.979 and 0.980. To show how closely groups selected at random might be expected to agree on the ratio, these 114 ob-

servers were arranged alphabetically and for each half of the list the mean and the median values were found. The two means were 0.985 and 0.995, that is, one per cent. different; the two medians were 0.978 and 0.982, or 0.4 per cent. different. In other words, in reproducibility the median is somewhat better than the mean. Even if the three color-blind observers are omitted, the mean of the two groups still differ by 0.8 per cent., being 0.982 and 0.990.

In order to test the constancy of the characteristic ratio of individuals, twenty observers repeated their measurements at the end of the test. The average deviation of an individual from his first value was 1 per cent., and the mean of the 20 differed by 0.2 per cent. in the two sets. Repeated measurements during the several months occupied by other parts of the work have indicated that this is the amount of variation to be expected in successive sets; consequently, the average deviation of an experienced observer from his mean value is usually well below 1 per cent. No definite indications of any important change in an individual's ratio have been found.

IV. MEASUREMENTS ON BLUE GLASSES.

The blue glasses mentioned presented a color difference equivalent to that between a 4 wpc. carbon lamp and a vacuum tungsten lamp at about 1.2 wpc. (8.2 lumens per watt). On such glasses measurements were made by all the observers with the flicker photometer and with the two forms of equality field. The latter both showed large variations in results and the general result is perhaps better shown by averaging out some of the individual errors. In order to do this the observers were arranged in the order of their characteristic ratios and averaged in groups; three of the extreme groups consist of 12 observers each, the others of 13. The results are shown in Fig. 3. The flicker photometer data are plotted at the bottom, and for comparison the curve drawn to represent them is reproduced as a broken line along with the data for the two equality fields. The curves drawn represent the least square solutions for the whole 114 observers, assuming a linear relation between characteristic ratios and observed transmissions. In the flicker measurements the change in transmission corresponding to 1 per cent. difference in ratio is

0.13 per cent., while the other curves show corresponding changes of 0.11 and 0.12 per cent.

The observers were somewhat arbitrarily classified by inspection of their settings on the equality photometer with regard to the consistency of settings (not their accuracy), and in Table I are given the mean results of the three classes, "a" meaning good,

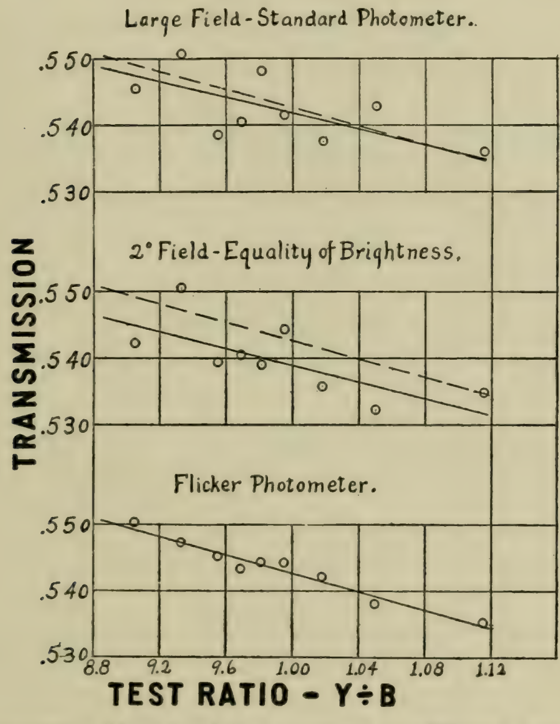


Fig. 3.—Transmission of blue glass (3G), presenting a color difference equivalent to that between 4 wpc. carbon lamps and 1.2 wpc. tungsten. Each point is the mean of 12 or of 13 observers. The lines represent the last square solutions for 114 observers. The flicker photometer curve is drawn with the others for comparison.

"b" medium, and "c" poor sets. The transmissions are all reduced to the basis of the mean ratio (0.99) so as to be strictly comparable, and the residuals are departures from the curves of Fig. 3; that is, the systematic errors due to individual characteristics have so far as possible been eliminated and the residuals represent largely the accidental errors in judgment.

TABLE I.—TRANSMISSION OF BLUE GLASS (3G) AND RESIDUAL ERRORS.

114 observers.

Class	No. of observers	Transmission (for ratio of 0.99) Flicker photometer	Large field equality	Small field equality	Mean residuals (per cent.) Flicker photometer	Large field equality	Small field equality
a	31	0.5430	0.5426	0.5404	0.5	1.2	1.2
b	58	0.5436	0.5429	0.5369	0.6	1.7	1.5
c	25	0.5437	0.5414	0.5454	0.7	3.2	3.5
Mean ...	114	0.5434	0.5425	0.5396	0.6	1.9	1.9

To test the reproducibility of results 20 observers well distributed with respect to ratio, most of whom had had considerable photometric experience, were selected to repeat these measurements. The individual observations are shown in Fig. 4, in

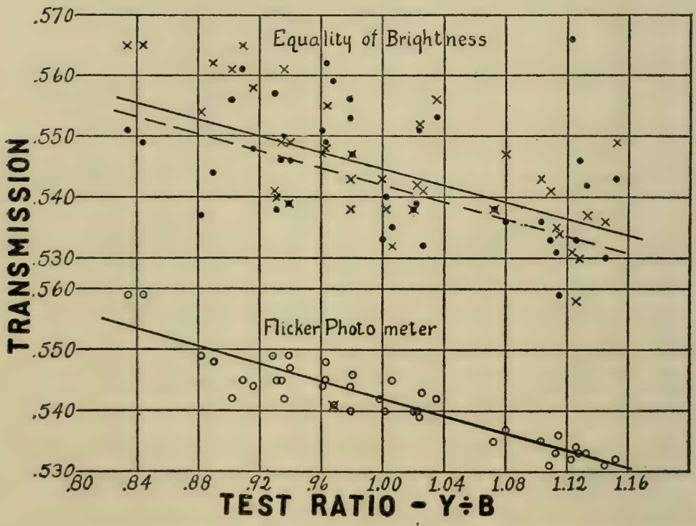


Fig. 4.—Transmission of blue glass (3G), two sets by each of 20 observers. The crosses represent measurements with a standard Lummer-Brodhum photometer, the dots those with a small field. For this group of measurements the average results with these two fields were the same. The dashed line is the flicker curve.

which as before the flicker curve is drawn through the other data for comparison. The average values for the transmission are given in Table II.

TABLE II.—TRANSMISSION OF BLUE GLASS (3G).
Two sets by 20 observers.

	Flicker	Large field equality	Small field equality
First set	0.5429	0.5431	0.5447
Second set	0.5422	0.5472	0.5456
Mean	0.5426	0.5452	0.5452
Av. diff. between two sets by each observer	0.4 per cent.	1.4	1.2
Mean of 14 observers	0.5427	0.5472	0.5436

It may be noted that both the groups of better observers in Table I find the transmission of the blue glass smaller with the small field than with the large, which is to be expected, but obtain higher values with the flicker than with either form of equality field. The twenty who were chosen to repeat the measurements happen, however, to read on the whole higher on the equality fields. Six of the twenty in the second set obtained results on one or both of the equality fields which differed by 2 per cent. or more from their first sets. If these six observers are omitted, the means of the remaining twenty-eight measurements are as given in the last line of Table II.

As the result of the 134 measurements, the average values for the transmission of this glass are 0.543 with both flicker and large field equality and 0.541 with the small field equality photometer. The greater certainty of the flicker values is shown by a comparison of the mean residuals in Table I, and the differences between sets in Table II. It may be remarked that some observers with practise develop the ability to repeat values very closely on the equality photometer, and such observers would make a much better showing for that photometer in a comparison like that of Table II. Unfortunately, however, such observers are comparatively rare and do not in all cases settle on a value in agreement with their characteristics as indicated by the flicker method.

The small field shows no material superiority over the large one. Table II would seem to indicate that it gave more reproducible results, but in Table I it will be seen that the residuals average the same for the two forms, while the small field shows the poorest agreement between groups of observers. The use of the small field was discontinued after this test.

Table I by itself would indicate a high degree of certainty in

the transmission as determined by the large field equality, but this certainty is reduced by the failure of the twenty observers to repeat their results or to agree with the larger group. Nearly half of the change shown by the twenty is due to a very poor set by one observer, but the fourteen (out of the twenty) who repeated most consistently got a value more than 0.7 per cent. above the mean of all the 134 observations.

Middlekauff and Skogland[10] have already called attention to the relation between the above values and those obtained in several other laboratories. This glass has a transmission 1.6 per cent. greater than the glass 3B included in their comparative measurements, and if the values assigned for 3B are correspondingly increased for comparison with the above (0.543) the results in different laboratories are 0.538 with a flicker photometer, and 0.546, 0.551 and 0.552 with Lummer-Brodhun photometers.

There are two differences in conditions which may in part account for the fact that the result obtained in the present work is below all the other Lummer-Brodhun values. In this work the photometer was used as an "equality" rather than a "contrast" field, and the illumination was much higher than that used in the other measurements. The difference probably arises, however, more from the fundamental uncertainty of equality-of-brightness measurements than from any of these systematic differences in conditions.

V. MEASUREMENTS ON A BLUE SOLUTION REPRESENTING THE COLOR DIFFERENCE OF CARBON AND GAS-FILLED TUNGSTEN LAMPS (ABOUT 0.65 WPC.).

This color difference is so great that most observers showed marked fluctuation in results from day to day with the equality photometer, although the majority made fairly good settings at any one time. Eleven observers made two sets on both photometers, using only the large field on the equality-of-brightness; on it each set consisted of three separate groups of readings, while on the flicker only two groups were made for each set, but the equality results were so erratic that the whole series of measurements with it were repeated. The individual sets are shown

[10] Paper presented at mid-winter convention of I. E. S., New York, February 10, 11, 1916.

in Fig. 5. The circles crossed by a line indicate sets in which means of groups showed marked discrepancies among themselves. The mean of the equality-of-brightness sets is about 5 per cent. above the flicker curve, but the only observers who repeated values at all consistently from day to day fall closer to that curve, and the most consistent observer has all four sets below it. Nevertheless, even if the more erratic sets are discarded, the equality values are definitely higher than those obtained by the flicker method.

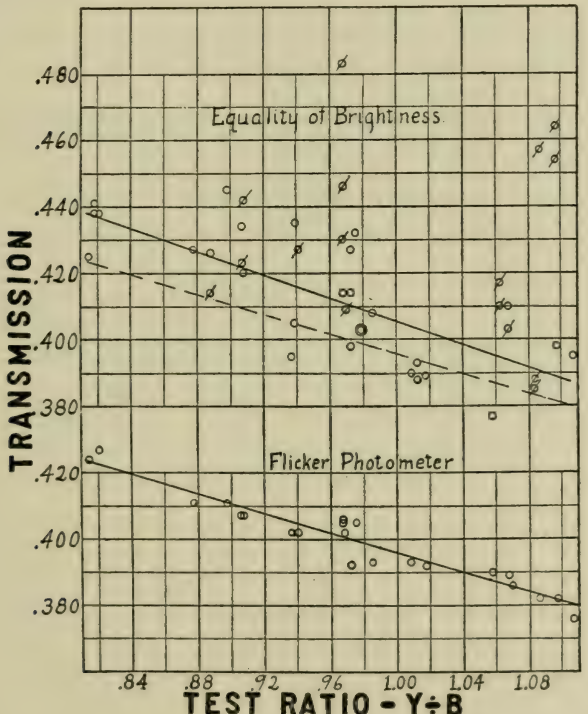


Fig. 5—Transmission of 1-cm. cell of 75 per cent. concentration Ives-Kingsbury nickel-ammonium sulphate solution. The crossed circles indicate measurements in which the groups of readings differed greatly. These are disregarded in drawing the curve. The published equation for transmission of this solution gives a value of 0.397 for this concentration.

For a ratio of 0.99 the mean transmission by the flicker photometer is 0.397; by the equality (including all sets) 0.417, the mean residuals being 0.8 per cent. and 3.5 per cent. The slope

of the flicker curve indicates a change in transmission of 0.38 per cent. for 1 per cent. difference in ratio.

It may be noted that this solution is the 75 per cent. concentration of Ives and Kingsbury's blue working solution,[11] for which the transmission calculated from the published equation is 0.3973 as determined for a characteristic ratio of unity, which should give 0.399 for a ratio of 0.99. The difference between the original calibration and the present check on this one point with the flicker photometer is therefore one half per cent. There are no other equality-of-brightness measurements available for comparison. Some further measurements on this solution are given in a later section of this paper.

VI. MEASUREMENTS OF PENTANE STANDARD AGAINST 4 WPC. CARBON LAMPS.

Fig. 6 shows similar data for the comparison of a carbon lamp with a standard operated to match the pentane lamp flame in

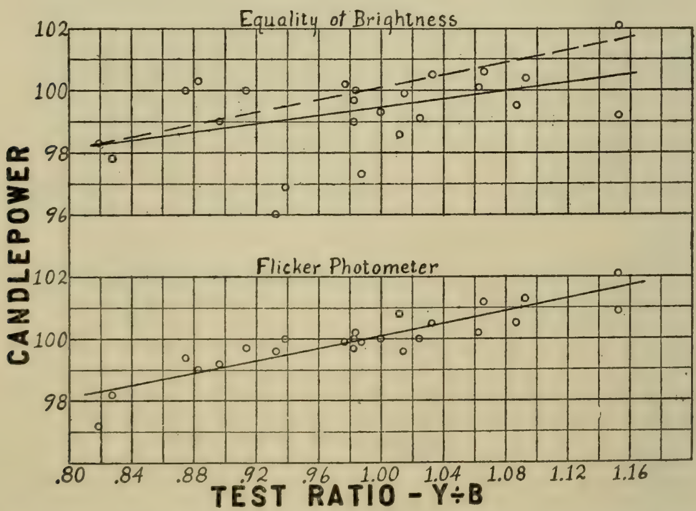


Fig. 6.—Measurements of the candlepower of a lamp matching the pentane flame in color, using a 4-wpc. carbon standard. The candlepower scale is chosen to make the average flicker photometer value 100.

color. This is in the neighborhood of 7.5 wpc. Here the slope is reversed because the light measured is redder than that of the

[11] TRANS. I. E. S., vol. X, p. 253, 1915.

carbon lamp. The change in observed candlepower corresponding to 1 per cent. in ratio is 0.1 per cent.

Each observer made two sets on each photometer, a set on the equality consisting of three groups of readings, but on the flicker of only two groups. The average difference between the two sets on the flicker was 0.6 per cent., on the equality 1.2 per cent.; the average residuals (departures from the curve) being 0.4 per cent. and 0.9 per cent.; in the two measurements of the characteristic ratio made by each observer, the average difference was as usual 1 per cent.

The mean value obtained on the equality is 0.6 per cent. below that given by the flicker photometer; and that this is not entirely due to accidental variation is indicated by the fact that 10 out of 12 observers varied in this direction.

The actual candlepowers found were 8.75 by the flicker and 8.70 by the equality photometer for a lamp whose value had previously been established as 8.70 by repeated calibrations in comparison with 4 wpc. standards on the standard Lummer-Brodhun photometer.

VII. MEASUREMENTS ON A BLUE SOLUTION AND ON MULTI-VOLTAGE STANDARDS.

At the completion of this work the lamps which had been measured at the various laboratories as reported by Middlekauff and Skogland were available, and in order to obtain a direct comparison of further flicker values with the results of those measurements, a few sets were made on the lamps at different voltages. As a convenient means of making the measurements with the standard illumination on the flicker photometer the values for the lamps were obtained indirectly by first calibrating, with the flicker photometer, cells filled with properly chosen concentrations of the Ives-Kingsbury blue solution which has already been mentioned, and then measuring the lamp on the Lummer-Brodhun photometer with approximate color match obtained by the cells. This procedure also gave a check on the calibration of that solution as published. The measurements made on each concentration of the solution were four sets by each of three observers, with slight corrections to put the results on the basis of the average eye giving a characteristic ratio of 0.99. The results

are given in Table III, the transmissions being percentages of the transmission of a similar cell filled with water. The values in column four are calculated from Ives & Kingsbury's equation.

TABLE III.—TRANSMISSION OF 1 CM. CELLS WITH IVES-KINGSBURY BLUE SOLUTION.

Equivalent wpc.	Concentration of solution	Observed transmission	Calculated transmission	Calc. trans. ratio = 0.99
0.65	0.75	39.5	39.7	39.9
0.85	0.47	56.4	56.5	56.7
1.00	0.42	60.0	60.2	60.3
1.2	0.34	66.7	66.5	66.5
1.4	0.28	71.8	71.6	71.6

Since the original calibration was supposedly based on an average eye corresponding to a characteristic ratio of 1.00, the degree of concordance obtained should perhaps be judged by comparison of columns 3 and 5, but as absolute calibrations of the solution columns 3 and 4 should be taken, and within the uncertainty of the present determinations made by the small number of observers mentioned the equation from which column 4 is calculated ($\log_{10} T = -0.539C^{1.03}$) is correct.

The last four of these solutions were used in measuring the lamps. The 75 per cent. concentration is very much bluer than is required by any of the voltages at which these lamps have been measured, and it was included only for a more complete comparison with the calibration curve, and with the previous measurements by a larger number of observers.

The results are perhaps best shown by comparison with those calculated from the Middlekauff-Skogland equations[12] based on Lummer-Brodhun measurements. The following table shows the percentage departure of the values found at the different efficiencies from the calculated values for each lamp. These measurements are equivalent to the direct comparison of lamps at the different efficiencies with a 4 wpc. carbon lamp. The differences given are positive when the flicker values are lower:

TABLE IV.—DIFFERENCES BETWEEN STANDARD LUMMER-BRODHUN AND FLICKER PHOTOMETER VALUES.

Approx. wpc.	1.4	1.2	1.0	0.85
Lamp 1	+0.15	+0.5	—	+1.45
Lamp 2	—0.05	+0.35	+1.7	+1.35

The large departure at 1 wpc. is quite inconsistent with all

[12] TRANS. I. E. S., vol. IX, p. 734, 1914; Bulletin Bureau of Standards, vol. XI, p. 483.

other measurements, and unfortunately the other lamp was not measured at this efficiency. The course of the variation should probably be considered independently of this point. The color match obtainable with this solution is far from being perfect, but the variations arising from this cause are not sufficient to explain the departure of this point from the other measurements. The significance of these measurements can best be seen by referring to the more recent paper by Middlekauff and Skogland, which includes them with results from other laboratories. It may be said that they agree very well with values obtained by Dr. Ives using a luminosity scale based on the flicker photometer, but fall considerably below all the results obtained with the usual Lummer-Brodhun photometer. The measurements already reported on the 75 per cent. concentration of the solution indicate that this difference probably will continue to increase as comparisons are carried to higher efficiencies.

VIII. CONCLUSION.

(a) *Effect of Individual Characteristics.*—The results presented above emphasize the fact that for accurate heterochromatic measurements a systematic choice of observers is essential. The system proposed by Ives and Kingsbury appears to be practical and reliable at least for color differences of the type dealt with in these tests. The average eye established is represented by a value of 0.99 for the ratio of the transmission of the yellow test solution to that of the blue solution under the specified conditions. The agreement with the original ratio assigned (1.00) is very good, especially since the latter was largely based on an indirect derivation of the average eye. It is suggested, however, that if the lack of symmetry in the distribution of these observers (as indicated by Fig. 2) is found to persist when larger numbers of observers are included, greater reproducibility of the normal ratio might be obtained by choosing as the normal not the average value, but the median, which in this case is 0.98.

The differences in observed values arising from individual peculiarities of course increase as the color difference increases. When comparisons are made directly with a 4 wpc. carbon lamp, a difference of 1 per cent. in the characteristic ratios of observers should result in approximately the following differences

in observed candlepower of a tungsten lamp at the various specific consumptions given:

Watts per candle	Percent candlepower difference
3.1	0.0
1.4	0.1
1.0	0.2
0.75	0.3
0.6	0.4

When plotted in terms of lumens per watt these data give nearly a straight line.

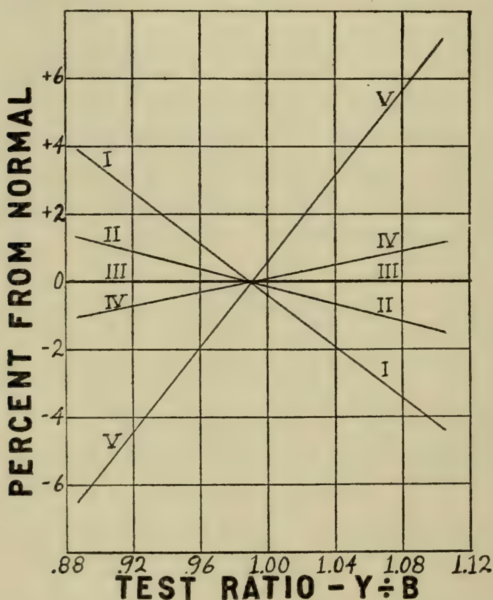


Fig. 7.—Percentage deviation from normal values corresponding to different test ratios when the light indicated is compared with that of a 4 wpc. carbon lamp. Curve I—0.75 concentration blue solution with carbon lamp, equivalent to tungsten lamp at about 0.65 wpc. The curve for the blue test solution practically coincides with this. Curve II—1.2 wpc. tungsten. Curve III—Color match, 4 wpc. carbon or 3.1 wpc. tungsten. Curve IV—Pentane lamp. Curve V—Yellow test solution.

Fig. 7 shows the per cent. deviation from normal values as a function of the characteristic ratio for the several color differences indicated. Thus an observer whose characteristic ratio $\frac{Y}{B}$ is 0.90, in measuring the candlepower of a 1.2 wpc. tungsten lamp against a 4 wpc. carbon lamp (3.1 wpc. tungsten) would assign to the tungsten lamp a value 1.2 per cent. too high. To a

0.65 wpc. tungsten lamp he would assign a value 3.5 per cent. too high. Of the 114 observers 19 (17 per cent.) would have obtained values for a 1.2 wpc. tungsten lamp differing 1 per cent. or more from the normal value; 70 (61 per cent.) would have departed 1 per cent or more from the normal in measuring a 0.65 wpc. tungsten lamp.

For measurements on color differences of this type it is not necessary to have a group of observers whose average ratio is normal; any observers may be used and their results corrected to the normal by use of curves similar to Fig. 7.

These curves can be summarized by the equation

$$I_n = \frac{I}{1 + m(R - R_n)}$$

where I_n is the normal value of a photometric quantity (such as candlepower, illumination or transmission), R_n is the normal characteristic or "test" ratio, while I and R are the values of these quantities found by a particular observer. m is an empirical constant, which may be either positive or negative and which depends on the color differences involved in the observation. It is the slope of the curves in Fig. 7. There may be slight systematic errors in the corrected values, that is, some observers may be always off the curve in the same direction, and consequently a number of observers should be used for highly accurate results. Not enough repeated measurements are at hand to show with certainty the average magnitude of these systematic errors, but they are certainly small in most cases.

On the average, measurements made with an equality-of-brightness photometer will show practically the same differences due to individual characteristics as those made with the flicker, but the erratic variations are often so great as to overshadow these systematic differences. It has been remarked that some observers develop the ability to make very consistent settings on the equality photometer. In the majority of cases such observers have been found to read close to the value indicated by their ratio, but this is not always the case.

(b) Comparison of the Flicker and Equality-of-Brightness Photometers.—With regard to certainty of measurement the flicker photometer shows a decided advantage even with small color differences. With more experienced observers, specially

selected, this advantage would probably be materially reduced, but would not be entirely lost, because even when an observer makes consistent settings on the equality photometer the relation of his settings to those of the normal observer is uncertain.

Trained observers are needed with either photometer, but with the flicker any observer of fair ability can make definite sets even with large color differences, whereas on the Lummer-Brodhun photometer it is only the exceptional observer who can do so. Extensive investigations at the English National Physical Laboratory[13] indicate that the final certainty of results is not increased by using the laborious "cascade" or step-by-step method of measurements to avoid sets with large color differences. Little is gained by such a procedure, unless the results of successive steps are agreed upon and made a practically independent standard for future use. This is the tendency of the present practise, and it appears that by this method fairly satisfactory standards of successively higher and higher temperature may eventually be agreed upon by interlaboratory and international comparisons. No one can say with what degree of accuracy the values of these standards can be reproduced from the fundamental standards a few years hence, and of course, this method applies only to those color differences which can be thus built up step-by-step with concrete standards to preserve the values at each step.

The flicker photometer on the other hand affords a means of relatively precise comparison between lights of all degrees of color difference, and makes possible the use of test readings for which average values, which should be highly reproducible, can be established.

In regard to relative results there appears to be no room for doubt that for sources having relatively high intensity at the blue end of the spectrum the values given by the flicker photometer as here used depart appreciably from those obtained with the Lummer-Brodhun as used in common practise, the difference probably being of the order of 3 per cent. at the higher efficiencies reached by the present gas-filled lamps. It is, however, hardly proper to assume that the results obtained by either photometer are "right" and anything different is 'wrong"; the equality-

[13] Paterson & Dudding, *Proc. Phys. Soc.*, London, 27, p. 263, 1915. (In particular p. 277.) Also *Phil. Mag.*, (6) 30, p. 63, 1915.

of-brightness method of measurement is undoubtedly more closely related to the way in which the light is used, but it is by no means established that that method correctly indicates the relative usefulness of two kinds of light. It must be recognized that there is no one definite "correct" ratio between the intensities of two lights of different color. The relative candlepowers assigned to a carbon and a tungsten lamp, for example, depend to some extent on the conditions under which the measurements are made. The specification of conditions of measurement must be more or less arbitrary, and the results obtained cannot be expected to be an exact indication of the value of different kinds of light under different conditions. Before we shall know much about the relative usefulness of different kinds of light much more experimental work must be done; an important requisite for such investigations or any others involving the comparison of the intensity of lights of very different color is a method which will enable different experimenters to make consistent measurements of the quantity which must serve as a basis for the comparison of their results. The usual equality-of-brightness method of comparison certainly does not fulfill this requirement; the flicker photometer at present is the most promising method available.

For the standardizing laboratory, which is expected to reproduce results after the lapse of years when the observers available may be entirely different, the flicker photometer (used under definitely specified conditions), with a systematic method of determining the relation of each observer to the normal, promises to give to heterochromatic photometry a certainty which has appeared quite unattainable with other instruments. Besides giving this probable increased certainty in future reproduction of values, it reduces very greatly the labor necessary to attain a given accuracy at the present time. Comparison of actual tests made in the routine work of the laboratory shows that even with relatively small color differences a given accuracy of reproduction of results requires several times as many measurements with the equality-of-brightness or the contrast photometer as with the flicker; moreover the tests considered were made by observers who had had much experience with the contrast photometer and very little with the flicker.

The authors are deeply indebted for the cordial assistance of many associates which has made possible the collection of the data presented. Particular acknowledgment is due to Mr. A. H. Taylor and Mr. E. M. Baker, who assisted in all the work.

DISCUSSION.

MR. L. C. PORTER: The question has been brought up as to whether there is a difference in the readings by trained and untrained observers. It seems to me probable that there will be considerable difference, but it will depend chiefly on the kind of training the observer has had. We recently had some tests made of lamps used for projection purposes. Filament temperature measurements were taken with a photometer, by color match. Immediately following these tests the lamps were placed in a projector, and illumination measurements taken with the same photometer, by the equality-of-brightness method. I find that those who have been accustomed to measuring by color match tend to favor that method when they are using the equality-of-brightness method, and vice versa. I also find that having taken a good many of both types of measurements I, personally, am liable to favor, for instance, the color match, if I have been using that for some time, and I have to work to overcome the inertia, so to speak, of one method of using the photometer when changing to another.

DR. H. E. IVES: I need hardly say to the Illuminating Engineering Society that this paper is of the very deepest interest to me, because of the amount of time and labor which I have expended on this same subject. In fact I am diffident about saying anything in the discussion other than to express my deep gratification that this subject is being investigated by the Bureau of Standards on behalf of the Research Committee of this Society. I am almost afraid that if I do say anything it may be interpreted as in the nature of fault finding or criticism in the narrow sense of that word. This, however, is very far from being the case. It is really an admirably carried out piece of work on this subject.

Of course anyone who has thought a great deal on any subject over a period of years obtains a certain perspective, so that if he were writing up an investigation of the subject, carried out no

matter where, he would lay his peculiar emphasis on some points more than others. The remarks I have to make are largely by way of indicating emphasis on certain points which the writers have not emphasized as much as I would.

For instance under the second heading, "Apparatus," we are told that in each case the photometer head was stationary and the lamp was moved by turning a wheel beneath the photometer. Now from my experience with people trying to work the flicker photometer, I feel that there is considerable danger of some laboratories after reading this paper setting up a flicker photometer, and having very discouraging results with it. The reason I have this fear is that one of the most important things in operating a flicker photometer is to have the means for varying the illumination as sensitive and frictionless as possible. I have used for this purpose a variable neutral tint screen with a rotating head which can be moved by a mere touch of the finger. One of the most admirable features of the apparatus as arranged at the Bureau was that the comparison lamp could be moved back and forth with a remarkably small effort on the part of the observer. When the observer looked into the instrument the effort he made in moving the comparison lamp did not make him shift his head from side to side or distract his attention from the field. I have never seen this necessary condition so well handled as at the Bureau, and I think it ought to be strongly emphasized. It is quite overlooked in many commercial photometers.

I would call your attention to the authors' remarks on the speeds chosen. The subject of the speed of a flicker photometer has been very much abused. Some of the early writers spent much time speculating on the possible effects on the results of using different speeds. Now the writers of the paper recognize correctly that there is just one speed for the flicker photometer, and that is the minimum speed possible without the observer being conscious of a flashing of two colors. This speed depends on the color difference, and should be found for each case. But as the time necessary to instruct every observer how to find that speed would have been prohibitive in the extension work at the Bureau, the method of using one speed, that to suit the average observer, was certainly the best for obtaining an average value,

even if the individual observers could not thus do themselves justice. The only reason I am bringing this up is because I am afraid of having the following statement misquoted: "the constant speed was adhered to partly because in the preliminary measurements there had been indications of slight changes of results when speeds much higher or much lower were used, particularly with the yellow solution," whereby the old purposeless discussion might be revived. As to the slight changes which were indicated, Mr. Kingsbury and myself have been working for the past year on a theory of the flicker photometer which appears to fit the known facts rather well, and also has brought out some new points of interest. Some of the results obtained will be published in the second and last installment in an early number of the *Philosophical Magazine*. Among other things that we noted in our work was that under the conditions where one illumination is held constant, and the other is variable, the position of the median of flicker is actually shifted first toward the fixed light for low speeds, then toward the moveable light for high speeds. The effect is exceedingly small and almost entirely drops out in working by the substitution method. It may be obviated by arranging to keep the field illumination approximately constant. Ordinarily this effect, which is not truly an effect of speed change at all, but one of average illumination change, may be neglected, but for precision work of the kind done at the Bureau of Standards it would perhaps be worth while to arrange to move both lamps instead of one, the one approaching the photometer head while the other receded.

Another point I would like to mention is in the discussion of condition No. 2 for the second photometer bar, in regard to the small field used in the equality-of-brightness photometer. This we note was surrounded by an illuminated diaphragm limiting the field as in the flicker instrument. The point about this is that such a small field surrounded by a bright border is a special case of equality-of-brightness photometry. In one of my early research papers on this subject, it was pointed out that as the color of the field surrounding the photometer field is changed, the judgment of the equality point is influenced. We have therefore in this small field as used, a special case; we have the case of a

surrounding field of the color of a certain incandescent lamp. For a complete investigation, a large number of special cases would have to be taken and the average results found.

A very important precaution in flicker work is fortunately observed by the writers, although it had not been emphasized before their work was done. It is another of the points we have found in our theoretical study, namely, that when the flicker photometer is used in this kind of work the zero of the instrument should first be determined by settings with no color difference. If the flicker field is optically perfect, free from all irregularities, the zero of the instrument will be exactly the same whether you run it slow or fast enough to obtain flicker. Now as a matter of fact I don't believe that one out of every dozen flicker photometers on the market is mechanically so symmetrical that the readings obtained will be absolutely the same when, with no color difference, it is used first as an equality-of-brightness photometer and then as a flicker photometer. This is due to mechanical defects in the instrument, specks, cloudiness in the field, or unequally fine dividing lines.

In regard to the point brought out that it was practically impossible to make a measurement with the two test colors using the equality-of-brightness photometer, I may say that the color differences so far as measured in the investigation are, as color differences go, exceedingly small. When the writers get to the point of measuring the luminosity of the spectrum and of spectral colors against a "white" standard, they will look back, I think, with amusement and contempt upon the terms they have used now in speaking of their color differences as "large" etc. The fact of the matter is that for real color difference the equality-of-brightness method is worthless as a practical method of measurement.

At the end of the discussion of Table II is a point of very great importance. We note that at this stage the small field was discontinued. It appears that this was discontinued from considerations of precision and reproducibility, not at all from considerations of the absolute value of the results. The reason I am interested in this particular point is that in the latter part of the paper there is a comparison of *an* equality-of-brightness and a

flicker photometer. The conclusion is reached that "the results with the flicker photometer here used depart appreciably from those obtained with the Lummer-Brodhun as used in common practise." The statements as made by the authors are exact and circumscribed, but we are practically certain to find them quoted as saying that *the* flicker photometer and *the* equality-of-brightness photometer give different results.* This is rather a personal matter with me because I have stood sponsor for the statement that under proper conditions flicker and equality photometers will read the same. I am rather jealous of the accuracy of the experimental results I have published from time to time. When it is a matter of drawing conclusions and making recommendations it is a matter of judgment, and every one has a right to his own point of view, but when it is a question of the actual behavior of an instrument or method it is always a great gratification to the person who has the privilege of publishing a result to see his result confirmed.

If I may be permitted to call attention to some of the points in which this paper confirms my work on this subject, I might mention the reversed Purkinje effect, which I believe I first noticed, also the statement I made some years ago that the precision and reproducibility of the flicker photometer were much greater than with the equality-of-brightness, for color differences. We find this claim confirmed incontestably in this paper where the mean residuals for work with many observers by both methods are no less than three times greater for the equality of brightness than for the flicker. Again, by way of checking our pioneer work by the same method they have here used, the authors have made a check calibration on our "Blue" Crova solution. Now while this involves color differences much greater than have ever before been made the subject of inter-laboratory comparison, their values check our published figures so closely as to be excellent inter-laboratory agreement even without any color differences being present.

Now to return to the matter of discontinuing the small field. This was unfortunately done just as the color differences were becoming fairly large and that is just when the small field or high

* Note added in correcting the notes of the discussion. Two leading technical journals have already made exactly this statement in reporting this paper showing my fear to be well founded.

illuminations were demanded. It is very well established that the two photometers approach each other in their behavior as the illumination is increased, and much more rapidly if the photometer field is kept small. I want to take this opportunity to emphasize that my recommendation has been specifically for high illumination and small field conditions and to state my belief that had the small field been here retained the difference between the instruments would certainly have been very much less if they did not disappear. I hope the authors will test this point in the near future. Perhaps the illumination I have specified is not high enough to secure complete agreement of the two methods. If so, then I would still advocate the use of such an illumination as would secure the agreement remembering that double or triple that now specified is still not high as working illuminations now go.

In their conclusion the authors have raised the question as to whether the concentrations of the test solutions should be chosen to give equal transmission for the average or for the median observer. I hope that before long they will give us the actual concentration of the two solutions, as I think they can, which would give a value of equality of transmission for what they decide upon as best criterion. The reason for this is that there are quite a number of allied problems in photometry particularly in physical photometry, whose further development depends on some decision as to the average eye to be assumed.

Finally I want to speak here of a possibility in the use of the flicker photometer about which I have always hesitated to speak before. I believe, as I said, that the best solution of the problem would be to chose certain illumination and field size conditions whose both types of photometer agree. Suppose for any reason it appeared undesirable to use such a field brightness so that two instruments do show a difference. Then there is a very simple scheme which might be used—there are enough people a little off average to make it possible to take as our normal flicker observer a group who would read the flicker instrument as normal observers would by the other method. It is also possible to put light color screens in front of the photometer eye piece and make it read anything we want, and yet preserve all the advan-

tages given by the precision of that instrument. I hope nobody will seriously consider these suggestions, as I think they are the least desirable way to meet the problem.

I again want to express my gratification on seeing this paper appear. It is a splendid contribution to this Society. It seems to me that we could not do anything better, if we had the money, than to establish a fellowship or paid assistantship to carry this work through. I understand it has to be sandwiched in between other work at the present time and wait its turn in the midst of routine not so important from our point of view. Remember that the whole science of illumination is based on the satisfactory solution of this problem. It would be an admirable thing for this Society to help the Bureau of Standards to further this research. If it cannot get money to do this, it should at any rate give all the moral aid it can.

DR. A. S. MCALLISTER: I have a point to bring up which is more a point of editing than anything else, but I wish to draw attention to it because it is something that ought not to be overlooked and I hope the proceedings will not be printed in this manner. On the ninth page the statement is made, "A rise in the efficiency of the lamp naturally causes a decrease in the observed ratio," and in the same paragraph, "The standard efficiency is 4.85 watts per spherical candle or 2.6 lumens per watt." In the first statement we would naturally think that the efficiency applies to the output, but upon reading the second paragraph it would leave one in doubt; I am sure the writer has the right thing in mind but I do not think it would be wise for those statements to appear that way in the printed TRANSACTIONS.

MR. E. C. CRITTENDEN: In presenting this paper I hoped that we might have more criticisms on it than has been given, for the questions involved are to some extent questions of expediency rather than of facts. We hope that the paper has added something to the available information on which a judgment can be based, but the nature of the problem of heterochromatic photometry is such that after all a decision as to methods and conditions of measurements must be more or less arbitrary, and in such a case discussion and interchange of opinions before making a decision is especially important. The establishment of standards

and standard methods is a matter in which it is well to make haste slowly. It is true, as Dr. Ives has said, that this work has had to be "sandwiched" in between other things, and the time available for such work is not unlimited, even in the non-commercial standardizing laboratory. We shall attempt to extend the work here reported, and shall welcome most heartily any contribution from other laboratories bearing on the problem.

One speaker has asked whether experienced observers obtain the same results as inexperienced ones, pointing out that with practise an observer tends to fix upon a more definite concept. Naturally the practised observer in general can make more precise settings; in other words to reproduce his values with a given percentage of accuracy the unpractised observer must make more measurements, but I do not see that this fact gives any reason for expecting a systematic difference between results obtained by experienced observers and those obtained by inexperienced persons. On the other hand, I am not prepared to say that in measurements with the Lummer-Brodhun photometer there is no such difference. In fact, of our 114 observers, those whom we would class as experienced in photometry did get a result slightly higher than the average of all.

In working up the data for the paper, 22 observers were selected as having had such experience as would justify giving extra weight to their sets if the purpose of the paper were to establish normal values for the Lummer-Brodhun photometer. Since this was not the purpose of this paper it was considered better not to give separately the results of these observers, but in view of a previous speaker's question they may be of interest, and they are therefore given below in comparison with the mean of the 114 observers.

TRANSMISSION OF BLUE GLASS (3G).

Observers	Flicker photometer	Large field equality	Small field equality
114	0.5434	0.5425	0.5396
22 "experienced"	0.5437	0.5462	0.5434

It may be noted that 0.546 is the transmission of this glass obtained by comparison with Glass 3B, using the value for the latter found by Middlekauff and Skogland. They used the type of field which we have called the large field equality, but made use of the contrast trapezoids as is usually done. Whether or

not there is a systematic difference between the results obtained by contrast settings and those given by strictly equality settings cannot be told except by testing a large number of observers, for on changing the method of judgment each observer must to a considerable extent re-establish his "definite concept" of what constitutes a setting, and some observers change in one direction, some in the other. My experience has been that the mean result obtained by a group of observers is not changed definitely in either direction by changing the method of judgment. When there is a considerable color difference in the field some observers can set more definitely if the contrast strips are removed. In this case the strips were not removed, but observers were asked to disregard them so far as possible and to set for equality of brightness in the central strips of the field. It is to be noted that the 22 "experienced" observers setting this way obtain exactly the same average result as Middlekauff and Skogland's group setting by contrast.

Referring to the data given above it may be seen that the 22 observers whose Lummer-Brodhun settings should have most weight on the score of experience obtain practically the same result with the two small fields (flicker and equality), and about ½ per cent. higher with the large field. In searching for such small differences, however, it is sometimes misleading to take averages of a small number of observers without considering the individual observations, for if most of the observers get small differences, a few erratic observers may throw the average results to one side or the other. Comparing the two small fields, of these 22 observers, 11 are higher on the flicker and 11 higher on the equality; as between the large-field equality and the flicker, 13 read higher on the former and 9 higher on the latter. While there is a definite preponderance in the one direction, it is evident that the magnitude of the difference is not established with much accuracy.

Referring to Dr. Ives' remarks about the discontinuance of the small field equality settings, I agree with him that if such settings had been carried through the measurements on the larger color differences the results would almost certainly have agreed with the flicker values more closely than the large field measurements

did. Practically, however, with these larger differences equality-of-brightness settings show such large variations from time to time and such wide differences between individuals that the results have very little significance; the use of the large field was carried as far as practicable because the tendency has been to use that type of photometer for all sorts of measurements and it was desired to correlate that instrument with the flicker, particularly with respect to differences between individuals as well as relative average values for the two instruments.

With regard to Dr. McAllister's remarks on the use of the word "efficiency" on the ninth page of the paper, I would say that by "a rise in efficiency" is meant an increase in the lumens output per watt of input. I must acknowledge the justice of his criticism of the use of the ancient wpc. ratings, but in extenuation I would say that all specifications of conditions for such work have hitherto been in those terms, and the particular purpose of the paragraph he has quoted is to give the data necessary to transfer the older specifications to the basis of lumens per watt.

MR. PRESTON S. MILLAR: Commercial organizations do not have the opportunity to carry out scientific researches of this kind and it is a matter of gratification that the Bureau of Standards is so ably fulfilling its function in research work.

As I understand the problem of heterochromatic photometry, accuracy depends first upon the employment of an average or normal observer, and second upon the standardization of all variables which may enter into the result. My own experience in heterochromatic photometry, dating back a few years, has impressed the thought that it is not so much an average eye as it is an average observer which must be employed. An observer looks at the field of an equality-of-brightness photometer which presents two surfaces differing somewhat in color. The problem is to bring the two surfaces to equal brightness. This involves the formation of a concept of the appearance of such surfaces when equally bright. The observer's eye may be quite normal, yet his result will be abnormal if the concept which he forms is not the correct one.

It has been my experience that as observers obtain more and

more experience in making heterochromatic tests, their judgment becomes better established, and when working together they tend to fix upon one and the same concept, and while I do not know any way to prove that such a consensus of concept is the correct one, yet I fancy it is likely to be more nearly correct than are early formations of judgment by observers who are not experienced in this particular class of work. This leads to the question which I should like to ask Mr. Crittenden; namely, Has any attempt been made to segregate observers with reference to the experience which they have had in heterochromatic photometry? Doubtless some among the 114 observers had little or no such experience, while others probably had a great deal. Would the same average value be indicated by the mean of the experienced observers as by the mean of the inexperienced observers?

DIFFUSING MEDIA—DIFFUSING GLASSWARE.*

Synopsis: The various types of diffusing glassware used to scatter the light from interior illuminants, windows and street illuminants differ in efficiency with differences in absorption and diffusing properties. The requirements in typical cases are outlined together with the properties of materials which meet them.

If a screen be placed between a source of light and an observer, the effect of the illuminant is altered in various ways according to the nature of the screen. In the following paragraphs plane and spherical screens, plane and spot illuminants, all degress of transparency and all classes of diffusion are discussed.

Spherical shell of diffusing material with source of light at or near its center. Such globes of opal glass and of clear glass roughened by sand blasting are frequently used on both interior and street illuminants. In some cases the globe appears as a uniformly bright ball, in others there is a brighter spot in line with the center of the globe. The effect is well illustrated in the illumination primer, "Light; Its Use and Misuse," published by the Society.

Suppose that a laboratory test has been made on a piece of the diffusing globe, that is, with perpendicular illumination by parallel light. The distribution curve of the transmitted light has been determined. From this the appearance of the globe in use may be predicted.

In Fig. 1 are indicated the relative positions of source, globe and observer.

In use, as in the laboratory test, the illumination is perpendicular to the screen. On the diameter is plotted the brightness distribution curve as determined on a small piece. On the tangent line is plotted the brightness distribution as seen across the surface of the globe. The geometrical relations are obvious. Take any line of observation as shown. From where this intersects the circular section of the globe draw a radius; the angle between this radius and the axis of observation gives the ordinate of the brightness distribution curve corresponding to the line

* Report No. 9, of I. E. S., Committee on Glare.

of view considered. The distribution of brightness over the globe is similar to the test distribution but somewhat expanded in the middle angles.

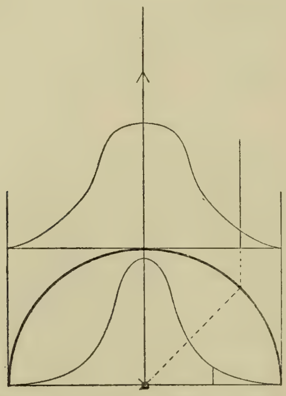


Fig. 1.—Action of a diffusing globe.

Plane plate of diffusing material with a small source of light behind it. Observed from a distance in a direction perpendicular to the plate, conditions may be represented as in Fig. 2. The illumination at any point of the plate will vary approximately as the inverse square of the distance, hence as the square of the cosine of the angle between the ray and the axis of observation. But the foreshortening of the surface causes it to vary as the cosine of that angle, hence as a whole the flux density varies as the cube of the cosine of the angle.

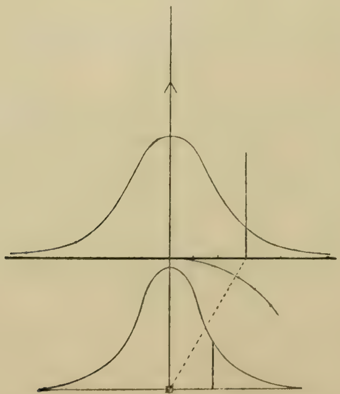


Fig. 2.—Action of a diffusing plate.

The brightness distribution curve for the plate may, therefore, be readily found from the distribution curve on a test sample. The relative brightness at any angle is read from the test curve, multiplied by the cube of the cosine of the angle and plotted on the plate curve at the corresponding angle. The curve shown in the figure corresponds to that for a plate of ground glass. If the plate is perfectly diffusing, the brightness falls off with the distance x from the axial point and the distance y of the source from the plate, according to the law B :: $x(x^2 + y^2)^{-3/2}$. This may readily be verified by substituting for the cosine and tangent their values in terms of x and y. The brightness gradient at a distance y from the axial point is dB/dy :: $xy(x^2 + y^2)^{5/2}$.

Sunlight on Diffusing Plane.—The third important case in practise is that of direct sunlight on a partly diffusing window pane. In this case the distribution of the transmitted light is precisely that obtained in the test of a small sample, the illumination being perpendicular and the observation at various angles.

Diffusing Materials.—Aside from lenses, mirrors, ribbed glass and similar selective materials the diffusing glassware in use consists either of clear glass with roughened or varnished surface or of glass containing minute bubbles or crystals. All ground and frosted glass is far from perfectly diffusing; the opal glasses are all highly diffusing.

In the following table are given typical data on brightness distribution for ground and opal glasses:

	100°	120°	140°	160°	165°	170°	175°	178°	180°
Glass, fine ground...	0.076	0.125	0.253	2.0	4.1	7.9	12.9	15.7	16.1
Glass, coarse ground.	0.055	0.077	0.201	1.7	3.6	5.6	11.3	13.2	13.2
Flashed opal, 0.2 mm.	0.28	0.33	0.37	0.40	0.40	0.40	0.41	0.42	0.42
Solid opal, ground ..	0.102	0.121	0.129	0.138	0.138	0.141	0.143	0.144	0.145

The surface layer of opal on flashed opal varies from 0.1 to 0.4 mm. thick. Good opal retains its highly diffusing property down to a thickness of about 0.05 mm.

Ribbed Glass.—Ribbed glass varies in scattering power from opal to ground glass; to the eye it presents a series of linear images each theoretically of the same brightness as the solar disk or whatever illuminant shines upon it, but practically considerably less on account of scatter by roughness or dirt. It has little to recommend it except perhaps for skylights. Within the

range of vision it and diffusing glass, upon which direct sunlight falls, are intolerable.

Absorption.—The light absorbed by diffusing glassware is, of course, an economic waste. The light reflected either enhances the effective intensity of the source or is directed above or below eye level where it is desired, but the light absorbed is dissipated as heat radiation.

The general relations between thickness, reflection and transmission are outlined in the first report on diffusing media. The absorption is approximately proportional to the logarithm of the thickness. In most cases sufficiently good diffusion may be secured with a loss of not over 10 or 20 per cent. by absorption.

In semi-indirect illumination and some other cases it is desired to bring the brightness of the diffusing surface to a given value even at some sacrifice of efficiency. This is accomplished by varying the diameter and thickness of the diffusing bowl and the relative distance of source of light from bowl and ceiling. Bowls should be designed with thickness, radius and specific density properly related to each other. Consider the case of any diffusing screen in which the scatter is not due to roughness of surface. If the incident flux density be F_0, then F_0R is the flux density of the light reflected, $F_0(1—R)$ of the light entering and $F_0T(1—R)$ of the light emerging from the back of the plate. Density, $D = —\log T$, T being the transmission. Now, by measurement R is the mean reflecting power (black backing) and relative front and back brightness, B 135 : B 45 say. Hence

$$T = \frac{B135}{B45} \times \frac{R}{1 - R}.$$

Calling the density divided by the thickness t (in millimeters) the specific density D_1

$$D_1 = D/t = -\frac{1}{t} \log T.$$

The specific densities of some well known materials are given in the following table:

	Specific densities
Print paper	4.0 -9.0
Drafting paper	2.6 -4.2
Ordinary pot opal	0.15-0.30
Flashed opal	0.25-0.35
Light (milk) opal	0.09

As an example of the use of this data suppose an opal bowl averaging 10 cm. from a source of light is to appear as bright as a ceiling 100 cm. from the source, $10^2 F_o T(1 - R_b) = F_o R_c$, hence, for $R_b = R_c = 0.8$, $\log T = 1.4$, hence the bowl would have to be about 5 mm. thick.

NELSON M. BLACK,
J. R. CRAVATH,
F. H. GILPIN,
M. LUCKIESH,
F. K. RICHTMYER,
F. A. VAUGHN,
P. G. NUTTING, *Chairman.*

VISION AND THE BRIGHTNESS OF SURROUNDINGS.*

BY PERCY W. COBB.

Synopsis: The paper outlines the results of investigation of visual acuity and difference-threshold, part of which were reported three years ago; and further results on difference-threshold obtained with apparatus of improved design which have cleared up points left in doubt by the earlier work. The earlier work investigated visual acuity and difference-threshold under three conditions as to surroundings: (1) dark and of brightness (2) 2.9 and (3) 42 candles per square meter, the test-object having various brightness under each. The newer form of apparatus involves a field in which the difference is brought about by the addition, by means of partial reflection, of a small brightness to one half of a uniform field. This makes possible the measurement of the difference directly, a much more accurate method than measuring it as a difference. The threshold-difference as a fraction of the field-brightness appears to have a very definite relation to the brightness-ratio, field to surroundings. The former is minimal when field and surroundings are equal and increases rapidly as the ratio decreases. As the ratio of field to surroundings increases the difference-fraction also increases, but slowly and to a limited extent. Proportionality in brightness appears to be the predominating factor. It is not the only factor since with proportionality maintained a higher absolute brightness gives a smaller threshold-fraction.

Three years ago the writer presented certain results obtained in the investigation of the subject indicated by the above title.[1] In the time intervening more complete data have been obtained in an exactly similar way and with the same apparatus and a report of the results of these will constitute the first part of this paper.[2]

The second portion[3] deals with a modification of the method, introduced to remedy certain defects inherent in the one first used and gives the results of work with it which seem to clear up points in which the former work was indecisive.

I.

The essentials of the experimental method were described in outline in the earlier paper and will be only briefly touched on here. The requirements assumed necessary for the purpose were:

(1) A surface of measurable and as near as possible uniform

* A paper presented at the ninth annual convention of the Illuminating Engineering Society, Washington, D. C., September 20-23, 1915.

1 Cobb, TRANS. I. E. S., June, 1913, pp. 292-297.

2 The detailed report of the work here reviewed is to be found in the following papers:
Cobb and Geissler, Psychological Review; XX, pp. 425-447.
Cobb, Ibid; XXI, pp. 23-32.

3 The second portion of this paper is to be considered in a preliminary report. Publication of a complete account of the work is reserved for a future date,

brightness, large enough and so disposed as to fill, except for the area of the test-field about to be described, the entire visual field. This is to constitute the visual surroundings for the test-field.

(2) A test-field which shall have a uniform brightness, controllable and measurable independently of the surroundings.

The criterion of vision under any particular condition as to brightness of test-field and surroundings was two-fold. The smallest angular separation under which a system of parallel lines would be recognized as such was one criterion. From this a measure of vision known as visual acuity may be derived. The other is the difference-threshold, that is, the smallest difference in brightness of the two halves of the field which may be recognized and named correctly as to direction.

The field during the interval between any two experiments visible as a surface of uniform brightness, was replaced, with the least possible change in the mean brightness or in any other particular, in the one case by a field of dark and bright lines of variable and controllable spacing. The results of the observer's judgments as to the visibility of these lines gave the least visual angle.

In the other case the original blank field was replaced by a similar one of which one half was either darker or lighter than the other by a small amount, likewise controllable and measurable, and in this way the difference-threshold was worked out.

The exact arrangement by which these changes in the field were accomplished, and the exact procedure by which the final results were arrived at will be found in the detailed report of this work, elsewhere published, and is briefly described in the second part of this paper. It will be only necessary to add here that the length of time that the field bearing the particular test feature was under observation was always three seconds. Before this, up to the instant of exposure, the observer was looking at a blank field of the same brightness as the test-field, and at the end of the observation-period the blank field automatically reappeared. He was then required to report, in the one case, whether he saw lines on the field during the exposure, or in the other, whether a stated half of the field appeared brighter or darker than the other. The blank field was before him during the entire course of a series except for the three-second periods during which the test-stimulus was being observed.

The results previously presented included those obtained with the surroundings of the test-object dark, the latter being varied from the lowest limit at which it was practicable to make observations up to the limit of the apparatus and these were compared with results taken under the influence of surroundings having a brightness of 41.9 candles per square meter. Under these surroundings the lowest brightness at which it was possible to work was far higher than under the dark. The results were those of two observers.

In the work since done, supplementary to this, the plan was the same except that the brightness chosen for the surroundings was 2.9 candles per square meter and the observations were taken only at brightnesses of test-object possible under the influence of those surroundings. Two observers were likewise used here, but only one (the writer) was common to the two pieces of work.

It is of interest to mention the fact here that both of the other observers gave better results as to visual acuity then did the writer, one of them to the extent of 40 per cent. under the conditions generally favorable to vision. For the other this advantage was slight (2 to 9 per cent.) except where the test-object had a brightness much lower than the surroundings. In two such cases the difference was 17 to 31 per cent. respectively.

With respect to the difference-threshold the advantage of the two other observers was conclusively shown only in those cases where the difference-threshold became large. These are: (1) with dark surroundings when the brightness of the test-object was low (0.5 candles per square meter or less) and (2) with bright surroundings and relatively low brightness of test-object. The difference between the observers in this respect may be summed up by saying that the writer required a test-field from two to five times as bright as did the others under these conditions in order to perceive an equal percentage difference between its two halves.

In Figs. 1, 2 and 3 the writer's results alone are shown graphically since they are the only ones comparable throughout. Fortunately as far as the results are significant in showing the effect of various brightness conditions these are fairly typical. For the several observers the changes in vision which will be

mentioned are in the same direction for the same change in conditions, the differences being quantitative and, except as stated, somewhat irregular.

Fig. 1 shows the variation in visual acuity due to the different conditions as to brightness of field and of surroundings. The ordinates represent the least visual angle under which the elements of the test-object are presented to the subject when they are just at the point of visibility. In this figure, therefore, and in the other figures as well, a small ordinate means better vision.

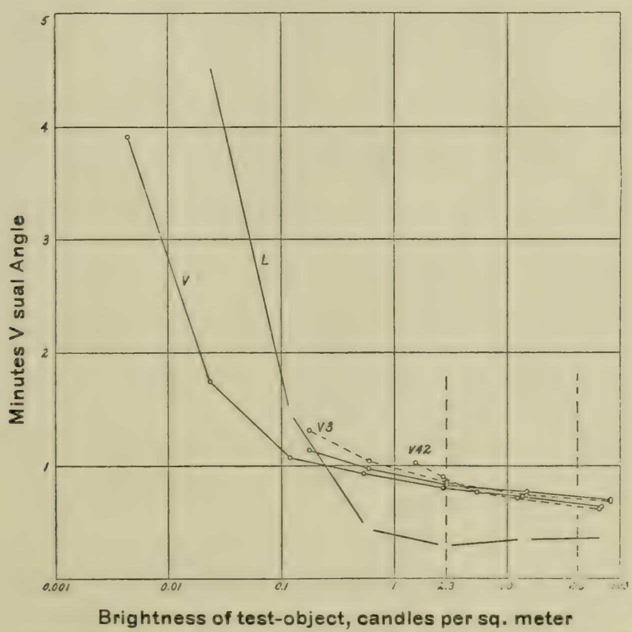


Fig. 1.—Least visual angle under dark and bright surroundings. The two curves drawn in broken lines (V3, V42) are the values obtained under surroundings of brightness approximately expressed by the numerals given, the curves drawn in solid lines (V) those obtained under dark surroundings. Of the latter the shorter is the one taken in connection with V3, the longer with V42. The discontinuous line (L) is the approximate course of the difference-threshold value for dark surroundings plotted as difference per cent. The brightness of test-object is plotted logarithmically, numbered as actual value.

Referring first to the curve V, it is seen that with dark surroundings, as the mean brightness of the test-object is reduced (from 83 candles per square meter) vision becomes less acute, at first slowly then rapidly. When the bright surroundings are

added (V3 and V42) it is seen that the curve follows a similar course but that the rise begins at a higher test-object brightness, and the divergence from the results with dark surroundings is greater the higher the brightness of the surroundings as shown by the upward tendency of the left-hand portions of the two curves. In these and in the other results it seems, so to speak, that the lower limiting brightness of the test-object is pushed up by the presence of the bright surroundings.

For visual acuity this does not occur until the condition is reached in which the brightness of the test-object is considerably less than that of the surroundings. In other cases, when the test-object is (generally speaking) at or above the brightness of the surroundings there seems to be in part at least a tendency toward better vision with the bright surroundings than without. In the cases shown in the figure this advantage amounts to 3 to 5 per cent., in only one case, with another observer, 9 per cent. The mean variation in such results was from 3 to 6 per cent. for the writer and 2 to 3 per cent. in the case of the other. So although these differences lie near to the margin of accuracy there seems to be a certain preponderance of evidence in favor of the view that they represent the fact. There is a possibility that the size of the pupil may have come into play here. A difference in the pupil must have been the case although the pupil was not measured and consequently nothing definite may be said.

Fig. 2 shows the difference-threshold for brightness. In general this shows the same principal change with the addition of bright surroundings as does visual acuity. Two differences are to be noted, however, first the differences in general shape of the curves for visual angle and for difference-threshold under dark surroundings, seen by the comparison of the curves V and L in Fig. 1 or 2.[4] While visual angle increases with decrease in brightness throughout, the difference-threshold does not do so, but seems to be fairly constant to a certain point, then rises quite sharply as compared with visual angle. And second, the rise in

[4] Plotting one of these as minimal visual angle, the other as difference per cent. is of course wholly arbitrary. A little study of the figure will make it clear however that the difference is not only apparent but characteristic, and cannot be made to disappear by any relative change in the scales of plotting.

the difference-threshold as the test-field goes below the surroundings in brightness is correspondingly sharp and proportionately greater than the rise in the least visual angle for the same change in conditions.

It might be expected that the less the experimental brightness-conditions are increased above the region where, with dark surroundings, the difference-threshold rises, the more restricted will

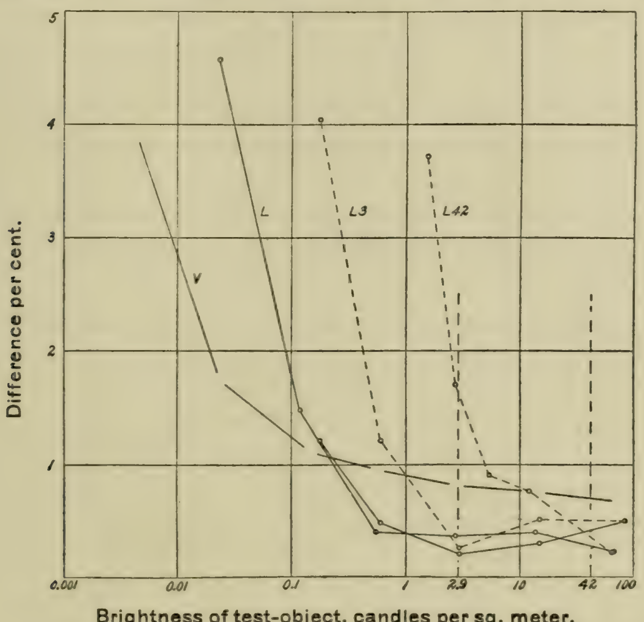


Fig. 2.—Difference-threshold under dark and bright surroundings. The two curve drawn in broken lines (L3, L42) are the values obtained under surroundings of brightness approximately expressed by the numerals given, the curves drawn in solid lines (L) those obtained under dark surroundings. Of the latter the shorter is the one taken in connection with L3, the longer with L42. The discontinuous line (V) is the approximate course of the least visual angle for dark surroundings plotted as minutes. The brightness of test-object is plotted logarithmically, numbered as actual value.

be the range of vision. It will make clear what is meant here to point out the way in which the results show this fact. If we estimate the point in the curve L3 where the threshold is 3 per cent. we find that there the brightness of the test-object is 0.275 candles per square meter, or about $^1/_{10}$ of that of the background. In the case of the curve L42 it is 1.86 or about $^1/_{22}$ of the background. To put the case concretely: if on a background of

80 per cent. reflection coefficient two grays are examined having about $^1/_{16}$ of this reflection coefficient and having a difference of 3 per cent. between them, that is of say 5 and 5.15 per cent. reflection coefficients respectively, they will be distinguishable under an illumination of 165 meter-candles and not under 11.4 meter-candles. These are the illuminations which will give such a background brightnesses of 42 and 2.9 candles per square meter respectively. Within the limits of the experimental conditions then it is fair to conclude that under high illumination a larger number of grays below the general brightness of the surroundings are to be distinguished than under low. This is in line with the well-known fact that a dim source, such as a single candle, leaves the dark corners of a room in obscurity while a more powerful source similarly placed and giving (approximately at least) the same distribution makes the remote details visible.

As to the behavior of the difference-threshold under a brightness of test-object equal to or greater than that of the surroundings it will be seen on inspection of the figure that the results are such that no conclusion is to be drawn.

There is still another measure of the performance of the eye which may profitably be brought in here. It is to be derived from the same data which have given us the threshold values just discussed. The threshold, as considered here, is the point at which the observer is probably capable of correctly naming the direction of the difference in brightness between the two halves of the field in 50 per cent. of the cases presented to him. The point is by no means a sharply defined one. In case, for instance, the difference-threshold is 1 per cent., he will probably report correctly in one half of the cases in which a 1 per cent. difference is shown him. On the other hand he will frequently give a correct report on differences smaller than this, and will also frequently overlook larger differences. There is thus the element of diffusion in the results which may be taken into account, and which is entirely distinct from the threshold as a criterion of visual sensitivity.

In a series of judgments it is found that when the difference is large in either direction the judgment is always correctly given. The limit of the region of mixed judgments for a single series

as here used is midway between the last of this group of consistent judgments and the first to deviate from it. Thus starting from the extreme end of the series where the judgments are constantly "right," a point is reached where the first "left" or "equal" appears. The limit of the region is then taken as midway between this first variant and the last constant preceding it. Similarly from the other end of the series as between the last "left" and the first variant from "left." Of the region so limited one-half is taken as its mean extent on either side of the point of equality. This obviously includes the threshold and a measure of the diffusion of the judgments and is here designated "M"

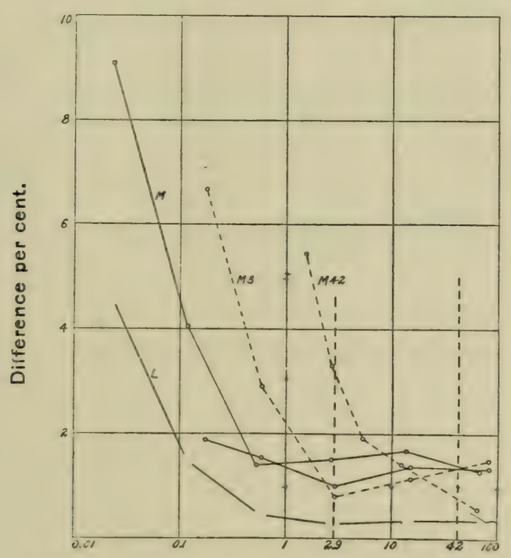


Fig. 3.—Region of mixed judgments under dark and bright surroundings. The two curves drawn in broken lines (M3, M42) are the values obtained under surroundings of brightness approximately expressed by the numerals given, the curves drawn in solid lines (M) those obtained under dark surroundings. Of the latter the shorter is the one taken in connection with M3, the longer with M42. The discontinuous line (L) is the approximate course of the difference-threshold for dark surroundings. The ordinates in this figure are all plotted to one-half scale as compared with the L-curves in Figs. 1 and 2; the abscissae are plotted logarithmically and numbered as their actual values.

(Fig. 3). The values there given are the means of the regions of mixed judgments for all the series in any case exactly as the thresholds are the means for all the series.

These curves show the same general changes in vision with changes in conditions as have been pointed out for least visual angle and for difference-threshold. In addition is to be noted what happens here when the test-field is of brightness equal to that of the surroundings. In each case (M3 and M42) the M-value is less than at the same brightness of test-field with dark surroundings. The curve M3 also shows that as the brightness of the test-field is increased from this point M tends again to approach the value it has with the surroundings dark, but this fact did not appear in the results from the other observer.

The results so far discussed show clearly the effect on vision of surroundings having a higher brightness than that of the object seen. The sensitivity of discrimination is thereby reduced, in a minor degree in the case of vision for detail, and only when the brightness of the test-object is considerably lower than that of the surroundings. In the case of difference-perception this reduction is more prompt and relatively larger in amount as the disparity in brightness increases.

On the other hand, although in no case is there any marked advantage as to vision of detail resulting from the presence of the bright surroundings, yet there is probably a slight gain here. As the subject of visual acuity is to be dropped at this point it may be well to sum up the conclusions that are to be drawn regarding it.

The present work adds some weight to the conclusion from practical experience, that bright surroundings are better for the vision of detail than dark. The only quantitative answer that can be given to the question "How bright?" is: certainly not brighter than the visual object. The difficulty that attends close eye-work upon an object seen in dark surroundings is probably not to be explained on the basis of reduced visual acuity.

II.

As to the question of how brightness-difference perception behaves under conditions in which the test-object is at brightness equal to and greater than that of its surroundings the foregoing results also give an intimation as we showed in the case of the M-values. It is to be added, however, that the threshold values were indecisive here and that the mean variations in the

cases of difference threshold and region of mixed judgments was large.[5] These considerations made a more thorough investigation of the difference-threshold desirable, and to obviate certain disadvantages of the old apparatus a new form was devised.

In the work above discussed the two halves of the field were two milk-glasses set side by side, or rather, those parts of them that were seen in photometric juxtaposition when viewed through a double prism. The two glasses were illuminated from the same source, and the difference in brightness between the two

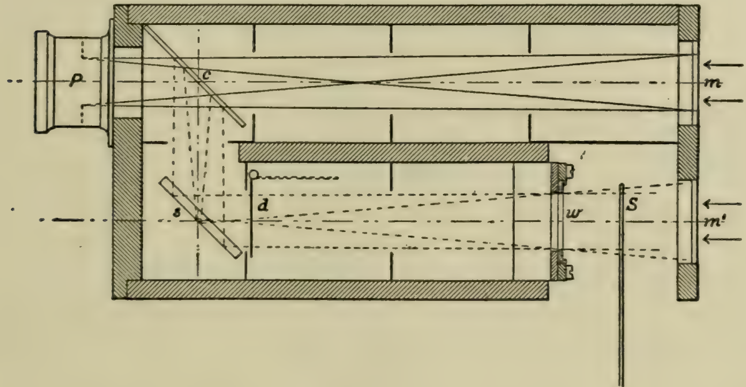


Fig. 4.—Arrangement for projecting field with separately measurable difference between the two halves. Compare with Fig. 5. The image of the window *w*, filled by the milk glass *m'*, is projected by partial reflection from a plate glass *c* to coincidence with the image of *m*. The same source illuminates both *m* and *m'*. By closing one-half of the window this addition is confined to one-half of the field. The sector-disc at *S* reduces the amount of the addition.

halves of the field was brought about by moving one of them in a direction at right angles to itself nearer to or farther from the source. This difference then had to be determined directly by subtraction of two measured brightnesses which were different only by an amount not far from the probable error of measurement; or, as was actually done, the variable brightness was measured at widely separated points and the intermediate values obtained by the inverse square law which was thus shown to hold approximately for the interval in question. But owing to fluctuations in the distribution from the lamp there was no abso-

[5] For the writer in the cases relevant to the conditions mentioned the mean variations expressed as fractions of the corresponding quantities are: for the threshold 74 per cent., for the region of mixed judgments 43 per cent.

lute point of equality, nor was there any fixed point of reference at which any stated difference could be known to exist.

The apparatus shown in Fig. 4 was devised to remedy these defects. The milk-glasses *m* and *m'* are illuminated by the same source. The lens *P* projects coincident images of *m* and of a window *w*, the latter by reflection, first from a silvered mirror at *s* and then from a clear plate glass at *c*. By a sliding shutter, either half or the whole of the window may be closed. Thus in the combined image a small brightness could be added to either half, and by stopping the appropriate path the original field or

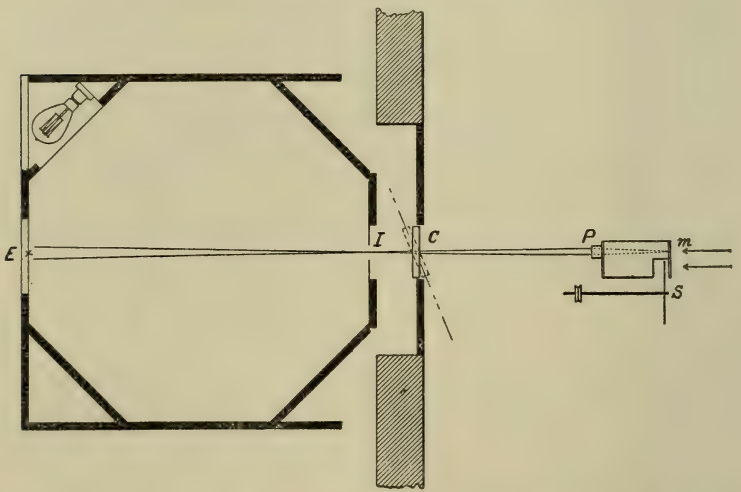


Fig. 5.—General arrangement of the apparatus. Two rooms were used. To the left is the hollow surface *E-I* illuminated as shown, which formed the surroundings for the field projected at *I* and seen from *E*. The condensing lens *C* was inclined as shown in dotted lines to avoid reflections of the interior of this surface. To the right is the device detailed in Fig. 4.

the addition could be measured as to brightness separately and directly. A variable sector-disk of 180° maximum opening at *S* was used to reduce the amount of the addition. Without the sector the addition was about 8 per cent. The exact fraction was determined separately for each setting of the lamp.

An ordinary reading glass *C* (Fig. 5) served as a condenser and made the image appear from *E* to fill the opening *I*, instead of being limited by the aperture of the lens *P* as would otherwise have been the case. This was accomplished by making *P* and

E conjugate foci of *C*. The opening *I* was 3.4 by 4.6 cm. and was 100 cm. from *E*.

The surroundings of the field were the interior of the box *E-I*. This surface was painted white and illuminated by a lamp or lamps as shown, through a milk-glass diffuser coincident with one of its oblique sides directly above the face of the observer (*E*). This portion of the set-up is identical with that used in the earlier work.

The observer views the image directly at *I*. A door *d* (Fig. 4) cuts off the addition until the observer makes contact with a key. This opens the door and closes it automatically after an interval, which was three seconds in the work to be discussed.

The experimental session consisted of 100 such observations, 25 different settings (namely, one with no addition, and 12 each right and left, the addition increasing by equal intervals) each shown to the observer four times; the entire 100 in shuffled order and exposed in groups of 25 with short rests between groups. Such a session occupied about half an hour, and five sessions constituted the work for each set of conditions for each of the three observers. Thus the values here given are derived each from a total of 1,500 judgments.

Fourteen sets of brightness conditions were investigated. These are in two groups which have one set, *o*, in common where the field and its surroundings are equal in brightness at about 17.5 candles per square meter. The first group includes also seven sets, *a* to *g* in which the brightness of the field was varied from 436 to 0, the surroundings remaining constant; the second six, *u* to *z*, in which the surroundings alone were varied from 122 to 0. The constant brightness was in both cases that of *o*, 17.5 candles per square meter. The upper limit in both cases was the limit of the apparatus.

The difference-threshold may be expressed in two ways. It may be expressed as a fraction of the field-brightness. This form is of the most practical use, since two surfaces of unequal reflection-coefficients always present a brightness-difference which is equal as a fraction of one or the other of them, independently of the illumination upon them, provided the distribution of light-flux is similar.

It is of no less interest, however, to see what the absolute value of the threshold-difference is as related to the absolute values of the field-brightness and the surrounding brightness. Weber's law states in effect that adding brightness to the field increases

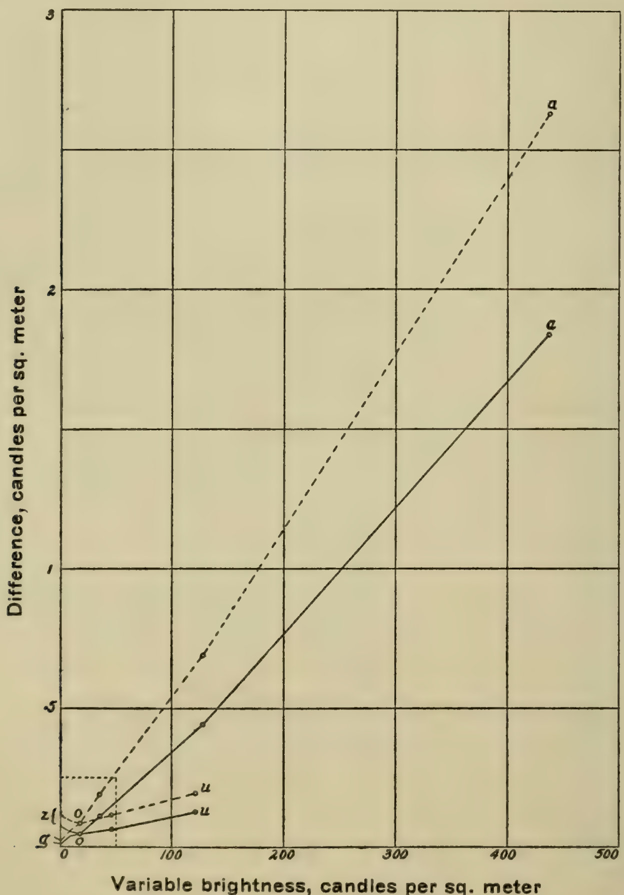


Fig. 6.—Mean difference-threshold and diffusion of same for different brightness conditions. The threshold (solid lines) and diffusion expressed as probable error (dotted lines) is given for two groups of conditions. (1) Surroundings constant at 17.5 candles per square meter, field variable (*a* to *g*) and (2) field constant at 17.5 candles per square meter, surroundings variable (*u* to *z*). All values plotted and numbered as their actual magnitudes.

the absolute value of the threshold-difference in proportion. Further, one would naturally think, that since by adding bright-

ness to the surroundings the field comes to appear darker, and that more brightness has to be added to it to get the same visual effect, that it would be found uniformly true that brightness added to the surroundings would reduce the effectiveness of the stimulation from the field and hence increase the value of the threshold-difference.

Figs. 6 and 7 show that this is not the case. The curves *uoz,*

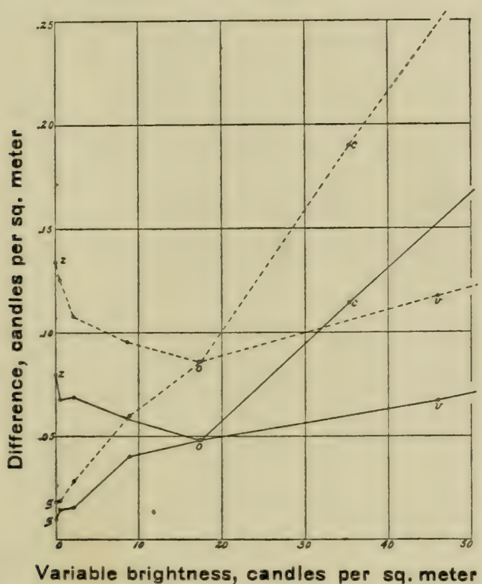


Fig. 7.—The portion of Fig. 6 included within the dotted lines, plotted to a larger scale. Explanation similar to that of Fig. 6. Surroundings constant, *c* to *g;* field constant *v* to *z*.

Fig. 6, and *voz,* Fig. 7, indicate the results obtained under the varying background with constant field-brightness, and it will be seen that the threshold decreases first as the brightness of the surroundings departs from zero, and continues to decrease until the surroundings have become equal to the field in brightness. From that point on the threshold increases with further increase in the brightness of the surroundings.

The other curves *aog* and *cog* (Figs. 6 and 7 respectively) indicate the results obtained by varying the field-brightness with constant surroundings. It is to be noted in the case of these that if a straight line be drawn from the origin through the point *o* it

will fall below the curve at all other points. The straight line would represent the threshold values demanded by a strict interpretation of Weber's law. So here again there seems to be a relative advantage at the point of equality of field and surroundings. These curves deviate from the oblique line in much the same way that the others deviate from the horizontal.

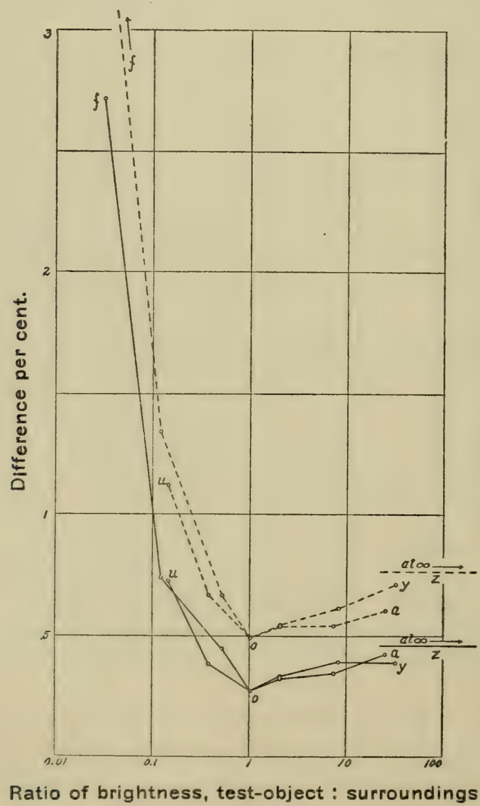


Fig. 8.—The relation of the fractional difference-threshold to the ratio between brightness of field and surroundings. The threshold (solid lines) and the probable error (dotted lines) per cent., field brightness as functions of the brightness-ratio of field to surroundings. The latter is plotted as logarithm, numbered as actual value.

This somewhat complex-appearing relation becomes much simpler if viewed from the standpoint taken in Fig. 8. The curves here indicate the threshold as a fraction of the field-brightness, which is plotted against the ratio that exists between

the field-brightness and the brightness of the surroundings. The two groups of results are thus plotted separately: in the curve *a* to *f*, the threshold-fraction becoming infinite when the field-brightness is reduced to zero at *g*; and in the curve *u* to *y*, the ratio of field to surroundings becoming infinite when the latter are reduced to zero in set *z*. The value of the threshold found in this last case is finite and its value is indicated in the plat.

The minimum threshold-fraction occurs at *o*, the point where the field and its surroundings are of equal brightness. As the field comes to be relatively less bright than the surroundings the threshold increases rapidly. On the other hand if the field is relatively brighter than the surroundings the threshold-fraction again increases but less rapidly and to a very limited extent. The same is true for both groups of conditions. Whether the difference between field and surroundings is brought about by varying the field-brightness or by varying the surroundings the two curves run much the same course.

It would seem from this that proportionality in brightness of the different parts of the visual field is the predominant factor in determining the sensitivity of vision. There is, however, one other consideration to be noted aside from this. The parts *ao* and *yo* of the curves represent conditions in which the field is brighter than the surroundings. It has been made so in the case of *ao* by increasing the brightness of the field over what it is at *o*; in the case of *yo* by diminishing the brightness of surroundings. On the whole then the curve from *a* to *o* represents higher absolute brightness than does the curve from *y* to *o*. And for similar reason *uo* represents higher brightness than does *fo*. It will be seen by inspection of the figures that from *a* to *o* the threshold-fraction is somewhat less on the whole than from *y* to *o*, and from *u* to *o* less than from *f* to *o*. That is, wherever the results may be compared, with equal ratio as to brightness between field and surroundings the threshold-fraction is less when the absolute brightness is greater, and what is said of threshold here applies even more strongly to the diffusion of the results. This would seem to indicate that the conditions of the experiments were on the whole rather below than above that range of absolute brightness which is optimal for vision.

One more point is to be mentioned as a conclusion from these experiments. That has to do with the comparison of the observers as to their visual sensitivity, and with the variations among them as to the changes in sensitivity induced by the changes in conditions.

Two of the observers showed extreme difference as to their values for threshold and its diffusion. Of these, M was unpracticed except for a limited number of preliminary observations not incorporated in the final results, and showed on the whole the lowest sensitivity. J, on the other hand, was the opposite extreme, showing about double the sensitivity of M, more or less, the variations of the two with changes in conditions being by no means proportional.

The third observer ranked between the two others, with a tendency toward quantitative agreement with M at low brightness or test-field relative to surroundings. In the opposite case, test-field exceeding the surroundings in brightness, C showed greater sensitivity than M and approached agreement with J. At *a* and *b*, where the field was brighter than the surroundings he surpassed J, but at *w, x, y,* and *z* where the difference between field and surroundings is in the same direction but both are at lower absolute brightness, J showed progressively more and more divergence from C in the direction of greater sensitivity.

It appears then from these results, much as from those discussed in the first part of this paper, that in going from what we may call mean conditions to low brightness of test-field, either relatively low as compared with the surroundings or absolutely low, C suffers a relatively larger loss of sensitivity than do the other observers.

Such differences between individuals may help toward the explanation of the fact that an illuminating system exactly right for one individual may be wrong for another, especially when we consider that these observers had normal or nearly normal vision, in one case with correction; and that many cases of unsuspected visual abnormality are undoubtedly at large, in which the variations might be much larger than in the observers used in this work.

DISCUSSION.

DR. C. E. FERREE: I am interested in Dr. Cobb's work because a great deal of the work of my own laboratory has been directed towards putting the eye under conditions that will guarantee uniformity or precision of response. This problem has been especially troublesome in color sensitivity. The factor influencing the eye's response the longest recognized is the one Dr. Cobb has been considering, namely, the brightness of the surroundings. If the surroundings are brighter than the object looked at, the object is darkened by physiological induction. If it is darker than the object looked at, the object is made lighter. This induction has a great deal of effect on the color sensitivity of the eye; whether or not it has an effect on visual acuity and brightness sensitivity is once more being investigated in the work of the foregoing paper. The work on this factor goes back to Aubert and Woinow, 1865, and has been so well recognized that the campimeter, a special instrument, was devised by Hess for controlling it. The apparatus described by Dr. Cobb is a modern form of the campimeter. Another factor is the effect of what the eye has rested on before it comes to its object or what is commonly called the pre-exposure. If the pre-exposure is darker than the object, the after effect is white. This mixes with the succeeding sensation. If it is lighter, the after effect is dark. In both cases the addition of the after effect exerts an influence on the sensitivity of the eye to color and changes its power of brightness discrimination and its acuity. A third important factor is the general illumination of the retina. This not only influences the sensitivity of the retina but also the effect of both of the other factors. One of my reasons for mentioning these factors here is because of the variability of result or the high mean variation obtained by Dr. Cobb in his experiments. In the experiments on brightness discrimination in his previous work the mean variation ranged from 34 per cent. to 126 per cent.; in the present work it was, I believe, about 74 per cent.

DR. P. W. COBB: A point I did not add in the paper was that the mean variation between the individual results for the different series in the recent portion of the work described in the second part of the paper was for the threshold on the average 29 per cent., and 17 per cent. for diffusion value.

Dr. C. E. Ferree: I get from a footnote in the present paper that the mean variation for the threshold is 74 per cent. and for region of mixed judgments 43 per cent.

Dr. P. W. Cobb: That was for the first portion of this paper.

Dr. C. E. Ferree: Then the 100 per cent. figure was for three years ago?

Dr. P. W. Cobb: Yes.

Dr. C. E. Ferree: That variation is so high compared with the change of results produced by changing the brightness of the surroundings, that it seemed to me greater than the change produced in the whole 14 variations in brightness, *i. e.,* greater than the entire change produced from beginning to end of the series through all the range of brightness variation. It is always my own teaching and practise that one can not draw conclusions with regard to results unless the mean variation is well within the variation or the change in results produced by change in condition to be tested, and that is why I am raising the point here. It seems to me that with regard to brightness discrimination the mean variation should be comparable with that which measures the precision in photometry. (For visual acuity it should be even smaller). If that falls within 1 per cent. of the result sought, I cannot understand the big mean variation in these cases. The results sought is in Dr. Cobb's case the difference threshold, not the brightness of the test field. His mean variation based on the result sought is not, therefore, 1 per cent. It ranges from 34 to 126 per cent. In all the threshold work I have ever done myself, difference threshold or liminal threshold, I have never encountered such enormous mean variations as he gets. If the photometric precision should fall within the 1 per cent. of the results sought, I do not see why, in these results, we should have such big mean variations. Among several causes, they might be due to conditions that influence the sensitivity of the eye. Three years ago Dr. Cobb and I had some discussion on the factor of pre-exposure. I did not think at that time he had made adequate control of pre-exposure. The treatment of that factor has been a great deal more emphasized in the description of the present work. In fact Dr. Cobb seems now to have overdone certain features. That is, as I understand, he had his

observer all the time he was not making the observation, which lasted three seconds, look uninterruptedly for a whole series of twenty-five observations at a field of the same brightness as the test object. Now that would mean that the eye would suffer an extensive progressive adaptation or change in sensitivity. That is the eye came to each individual test in a different state of adaptation or sensitivity. Our own method of controlling the factor—and we worked quite a long time to get a small mean variation—was that there should be a constant rest interval between each observation during which the eye was allowed to recover its sensitivity under a low illumination (always constant). To prevent any temporary after effects from the change back to the test field the eye was always exposed for a certain length of time, constant for each observer, to a field of the same size and brightness as the test field. In this way all of the variable effects of pre-exposure were eliminated and the eye was brought to each observation in the same state of sensitivity.

Dr. P. W. Cobb: I only wish to answer on one or two points that apply directly to the conditions of this particular problem. As to the question of mean variation; where I have given that, I have expressed it as per cent. of the difference threshold itself. For instance, if the difference threshold is one one-hundredth, expressed fractionally or absolutely as you like, the mean variation is expressed as so much per cent. of that quantity; that is, a mean variation of 30 per cent. would fall within that 1 per cent. difference, or as it is here expressed, would be 30 per cent. of the threshold difference.

Dr. C. E. Ferree: The threshold difference itself is the average of all the settings?

Dr. P. W. Cobb: The average of all the settings. Say one side of the field was 100 units brightness and the other, at the threshold, was 101, and the mean variation was 30 per cent. The threshold difference is then one unit or, expressed as a fraction of the absolute brightness, 1/100. A 30 per cent. mean variation, expressed as in this paper, would then be either 0.3 unit of brightness or as a fraction of the absolute brightness 0.3/100. Since the threshold was different for the different sets of conditions, I preferred to express mean variation as a percentage of the threshold difference. In that case it is also in-

dependent of whether the threshold is expressed in absolute terms or as a fraction.

Dr. C. E. Ferree: How does that compare with your experimental variation change produced by change in conditions?

Dr. P. W. Cobb: Of course each one of these results given here is the mean of five results obtained respectively from five groups of experiments. The mean variation is comparable with the probable error of a single one of these. The probable error of the mean result is much less than that of a single one. The more results we have, the less the probable error of the average becomes. I do not, offhand, know the formula for the relation.

The Chairman: But that has to fall within the mean variation, if you were drawing conclusions? I simply ask this as a guide to what the conclusion would be.

Dr. P. W. Cobb: In addition I would like to say that from the fact that the results plot in a consistent way when taken for the entire fourteen sets of conditions we can draw some conclusion as to their reliability. The regularity or otherwise with which they plot is some indication as to the extent of accidental variations.

Now, as to the matter of pre-exposure or the question of adaptation—if we consider the period required to run 25 exposures, one may have the subject do as I did; that is look at the blank field, with its surroundings under brightness conditions, as near as possible to those of the actual observation-time, continually during that period, which happened to be seven or eight minutes. In that case, of course, his adaptation from whatever it initially happens to be, will gradually approach a constant level corresponding to the experimental brightness conditions which are under investigation. That depends on the field and the surroundings that he is looking at. I prefer in experimental procedure to do that rather than between each two exposures have the subject look at something else which does not represent the experimental conditions, and then look back at the field and its surroundings. It is a matter of opinion here, I suppose but I preferred to conduct the experiment with as few extraneous factors as possible.

Dr. C. E. Ferree (Communicated): In answer to my objection to his method of controlling the variable influence of pre-

exposure, I understood the author to say on the floor that his procedure brought the eye to a constant state of adaptation. The only way that bringing the eye to a constant state of adaptation to the brightness of the test object could be introduced with any logical bearing on the control of this factor would have been to have done it before the first observation was begun. Then the eye would have had a constant not a changing sensitivity throughout the work. This was not done however, and even if it had been, it would have meant that the work would have been carried on with the eye at a very much reduced state of sensitivity, especially for test fields of high brightness. Also I would say that any precaution taken to bring the eye to constancy of response cannot be put in the class of extraneous factors.

As I stated on the floor, one of my reasons for bringing up the question of the control of variable factors has been because of the large mean variations which were gotten in the tests. When one consults the table of results from which the curves given in this and a preceding number of these TRANSACTIONS have been plotted (see *Psychological Review,* 1913, XX, 425–447; 1914, XXI, 23–32; *Journal* of Franklin Institute, Aug. 1915, 235–237) some rather startling facts are revealed with regard to the precision of the work. The following ranges of mean variations are found in the different series of results presented in these tables: 41 to 100 per cent., 37 to 107 per cent., 48 to 102 per cent., 43 to 100 per cent., 67 to 102 per cent., 74 to 98 per cent., 68 to 71 per cent., 97 to 98 per cent., 78 to 126 per cent., 52 to 81 per cent., 64 to 99 per cent., and 34 to 93 per cent. I understood the author to explain on the floor that these mean variations were not really large because they were computed as percentages of a small quantity, the difference threshold. That they should be computed on the average value of the results sought, namely the difference threshold, is not at all surprising for that is the usual way of estimating the mean variation. Moreover, such an explanation misses entirely the point of the mean variation, for it is not its absolute value, that is of significance but rather its relation to the average value from which it is the mean throw or average deviation. Results, therefore, in which the mean throw or deviation from the result sought ranges from 34 to 126 per cent. of the result itself, in work where scientific methods are

used, can not well help but be an occasion for no small amount of surprise. In fact, one scarcely knows what a determination of a difference threshold means when the average throw in either direction might be from 2 to 26 per cent. greater than the average value of the difference threshold itself. That is, in these cases the judgment of just noticeably lighter might have been made either when the surface judged was on the average actually 2 to 26 per cent. darker than the standard surface or when it was lighter by an amount on the average from 2 to 26 per cent. greater than twice the average value that was obtained for the difference threshold; and these, it will be remembered, are only the average values of the deviations. The maximum throw in either direction obviously must have been considerably greater.*

* I also understood Dr. Cobb to justify the size of his mean variation by saying that it falls within 1 per cent. of the value of the test field itself. The following things may be said of this. (1) The statement is not true for several of his series, and even if it were true for all of the cases given, it would be so only because the difference threshhold itself falls within 1 per cent. of the value of the test field and therefore a mean variation of as much as 100 per cent. of itself wouid fall within 1 per cent. of the value of the test field. (2) It is quite irrelevant to the point in question whether the mean variation falls within 1 per cent. of the value of the test field, or not, for its relation to the test field is not what determines whether a satisfactory degree of precision has been attained in the work. This can be determined only by comparing the size of the mean variation with the average value of the result sought and with the variation produced by changing the condition to be tested. If it does not fall within a small per cent of the former and come well within the latter, the results are not accepted as satisfactory. The mean variation would never be compared for this purpose with the value of the test field. Such a comparison would be made only in case there were some special need for doing so in the presentation of the results.

I presume Dr. Cobb's purpose here is to show some analogy between the size of the mean variation and of the 1 per cent. which is accepted by some as the outside limit of precision in photometry. Before accepting this or any analogy based on a comparison with photometry as having any significant bearing on the point in question, the following facts should be given consideration. (1) The photometrist's 1 per cent. expresses a ratio between the mean variation and the result sought. This ratio in Dr. Cobb's experiments ranges from 34 to 126 per cent. There is thus no similarity in result when both follow the same rule for determining precision. A similarity appears only when Dr. Cobb's mean variations are estimated on the value of the test field which is not in accord with the accepted rule of estimating precision. (2) If the absolute values of the mean variations are to be compared it should be remembered that a larger mean variation can be tolerated in photometry than in a determination of difference threshholds because the size of the result sought in the former case is so very much greater. Moreover, a greater mean variation should be expected in photometry for two reasons. (a) In photometry the setting of the instrument may range through a difference threshold on either side of the equality point, while not nearly so great a range of variation is probable in the determination of a difference threshold, more especially if the method of limits is used as was the case is the above work. And (b) none of the more careful precautions (psycho-physical and for control of sensitivity) are employed in photometry that are recognized as necessary in the determination of a difference threshold. The mean variations gotten by Dr. Cobb are, I may say, many times greater than any I have ever obtained myself in a somewhat extensive determination of the difference threshold for both colored and colorless light at different times with quite a wide range of observers; and greater than any that have yet come to my knowledge in the work of others.

While it does not need further consideration therefore, to show that these variations are astonishingly large on whatever base they are computed, still a fair evaluation of the worth of the experiments requires also that the mean variation be compared with the variations produced by changing the conditions to be tested. This comparison can not be made with satisfactory precision for the results in question because of the plan of work employed by Dr. Cobb. That is, his experiments are so planned as to give him no information for any observer for each intensity of test field employed as to what the value of the difference threshold would have been without the effect of a difference in the brightness of the surroundings, *i. e.,* with surroundings of equal brightness. Without this information definite conclusions cannot be drawn with regard to the effect of difference in brightness of surroundings in any given case, because there is no value of the difference threshold representing a zero effect on which to base the comparison. Therefore, since no direct estimation can be made in the several cases of the effect on the difference threshold of a difference in the brightness of surroundings no satisfactory comparison can be made of the normal variation of the test and the variation that is produced by changing the conditions to be tested. A satisfactory check cannot thus be had on the effective precision of the results obtained. However, as nearly as we are able to determine from the data that is presented in the three tables in which mean variations are given, the mean variation is greater than the variation produced by changing the conditions to be tested in about 50 to 75 per cent. of the number of cases given in the various series for the different observers. I need scarcely point out that in experimental work changes are not considered significant unless there is no overlapping of values when the mean throw is applied on either side of each of the several members of the series. Should this criterion be applied to the various series of results obtained by Dr. Cobb, I fear that the percentage of changes that could be accepted as significant as the series are given would be low. In any event it is an essential part of careful work where there are such strong grounds for doubt for Dr. Cobb to show that the variations produced by changing the conditions to be tested are significant and thus justify the use of the values he obtained for the plotting of curves.

In the work on visual acuity a better case is made. While the mean variations, which range from 1.5 to 13 per cent. of the results sought, namely, the space threshold or least discriminable angle, average 4.5 per cent., might well be considered unnecessarily high, still they are so much smaller than those obtained in the work on brightness discrimination, where they range from 34 to 126 per cent. of the values sought, average 74.2 per cent., as to be worthy of comment. Again, however, an inspection of the results shows that, so far as can be told, not even in this division of the work can all of the changes recorded and plotted in the curves be considered as significant. In Table I, dark surroundings observer G, all the results are significant; observer C, 83.3 per cent. are significant. In Table I, surroundings 41.9 candles per square meter, the results of 75 per cent. of the changes for both observers G and C are significant. In Table II the results for each of the four changes employed are significant. In Table III, dark surroundings, observer J, all of the results are significant; observer C, 25 per cent. are significant. In Table III, surroundings 2.87 candles per square meter, the results for 75 per cent. of the changes for both observers J and C, are significant. The propriety of plotting results to represent changes due to variations in the conditions tested in an experimental series in which the results for only 25, 75, or 83 per cent. of the cases included can be considered as significant is again, it is scarcely needful to point out, open to question.

Dr. P. W. Cobb (In reply to the communicated discussion of Dr. Ferree): For a reason which I will state later I do not propose to reply in this place to Dr. Ferree at as great length as the above given discussion would seem to demand. I wish especially to correct a misunderstanding that arose on the floor and to deny a certain imputation that has arisen in consequence.

In the above-given report of the discussion from the floor, after the fourth appearance of his name and beginning at the eleventh line of the paragraph, Dr. Ferree says:

> It seems to me that with regard to brightness discrimination the mean variation should be comparable with that which measures the precision in photometry. . . . If that falls within 1 per cent. of the result sought I cannot understand the big mean variation in these cases. The result sought is in Dr. Cobb's case the difference-threshold, not the brightness

of the test field. His mean variation based on the result sought is not, therefore, 1 per cent. It ranges from 34 to 126 per cent. . . . If the photometric precision should fall within the 1 per cent. of the results sought, I do not see why, in these results, we should have such big variations.

In the two paragraphs following, attributed to me, I stated the simple fact that I had computed the percentage mean variations on the difference threshold as a base, having misunderstood the above as implying that they had been otherwise computed. Aside from this these paragraphs are not relevant to the discussion.

The mistake is initially mine. An unfortunate consequence of it is that I am misrepresented in Dr. Ferree's communicated remarks as having raised the absurd contention that a sufficient criterion of the significance of the results consists in the mere fact that the mean variations are of less magnitude than the difference thresholds to which they apply.

The intended meaning that, in the light of subsequent events, I have been able to draw from the remarks I have just quoted seems to depend on this proposition; that since the mean variation in photometric settings is found to be about 1 per cent. of the quantity sought, the mean variation in difference threshold determinations may reasonably be expected to bear about that same relation to the difference threshold. That is, an approximate proportion could be anticipated between the two quantities measured and their mean variations. In the absence of relevant facts such a predication has only an impossible analogy in its support and is readily misunderstood in a serious discussion.

I think anyone who will read Dr. Ferree's communicated remarks and also the paper to which they apply will find that I have been conservative in drawing conclusions, and that in questioning the significance of the experimental differences found I may rightly claim priority, for just as the experimental differences are relatively small the conclusions are qualified. I might add that the probability of the significance of an experimental difference is not to be estimated by any such simple rule as he states: "that . . . changes are not considered significant unless there is no overlapping of values when the mean throw is applied on either side" of two quantities to be compared. A fundamental principle in the reduction of observations is that the

precision of the average of a number of measurements is greater with a larger number, while the mean variation of the single measurements undergoes no consistent change with change in number.

I might add that Dr. Ferree confines his attack entirely to the results given in the first part of the paper, concerning which I had something of similar import to say in the first paragraph of the second part; and that the "startling facts" of which he speaks were none of them drawn from the *Journal* of the Franklin Institute, August, 1915, since the article so referred to is a preliminary communication (on the work of the second part) and as such gives no information as to the precision of the results.

As to the results of the second portion of the paper, I stated from the floor (offhand from memory) that the mean variations averaged 40 per cent. This is no doubt still too large to warrant serious consideration of the results at Dr. Ferree's hands, but I feel that I am entitled to the difference—which has not been accorded me. As a matter of fact the true figure is 29 per cent. and it stands so corrected in the report above.

I wish to thank Dr. Ferree for having called attention to this point in no uncertain tones. The last mentioned work is not yet ready to go to the printer for final publication, and his remarks have confirmed me in the intention of adding a discussion which will answer the question of the probable significance of the experimental differences.

DAYLIGHT ILLUMINATION, AND THE INTENSITY AND DURATION OF TWILIGHT.*

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Synopsis: Photometric measurements of the intensity of the illumination on a horizontal surface from sunlight and skylight, made by the author at Mount Weather, Va., may be classified as follows: (1) the daylight illumination with a cloudless sky; (2) the illumination from a clear sky alone; (3) the daylight illumination with an overcast sky; (4) the twilight illumination; (5) by computation, the illumination by direct sunlight on a surface normal to the incident rays. This was found to exceed (1), except for from four to eight hours in the middle of the day between April and August, inclusive. Compared with (1), (3) is sometimes one half, is frequently one third, but may be only 1 per cent. as intense. With increased haziness of the atmosphere (2) is frequently doubled, although at the same time (1) is diminished. Astronomical twilight continuous until the sun is about 18° below the horizon, and civil twilight until it is about 6° below. The latter is associated with the purple glow sometimes seen in the west after sunset. A table gives its duration at different latitudes. At latitude 50° N. at the time of the summer solstice it lasts fifty-one minutes, as compared with twenty-six minutes at the equator. Photometric measurements (4) show that during this interval its intensity diminishes from about 100 foot-candles to less than 1 foot-candle, after which artificial lighting is necessary for the safe conduct of outdoor occupations.

PHOTOMETER EMPLOYED, AND ITS EXPOSURE.

The photometric measurements presented in this paper were made with a Sharp-Millar photometer at Mount Weather, Va., between September, 1913, and September, 1914, inclusive. The summit of the Blue Ridge at Mount Weather is about 1,725 ft. above sea level, and 1,200 ft. (366 m.) above the valleys immediately to the east and west. The latitude is 39° 4′ north. In Fig. 1 at *B* is shown the small shelter on the roof of the physical laboratory in which the photometer was exposed. In Fig. 2 at *C* is seen the milk glass test plate on the end of the elbow tube of the photometer, the rest of the instrument being inside the shelter and under the black cloth cover. The glass *C* is above all surrounding objects except the wind vane. At *D* is shown a solar screen that was used at times to shade the glass *C* from direct sunlight, so that measurements could be made of the

* A paper read at a meeting of the Pittsburgh Section of the Illuminating Engineering Society, Cleveland, Ohio, February 18, 1916.

illumination from diffuse skylight alone. In the figure this screen is shading a Callendar pyrheliometer, at *A*, so as to obtain a measurement of the heating effect of the diffuse radiation received from the sky. When unshaded this pyrheliometer measures the heating effect of the total radiation received from both sun and sky. These measurements shall be referred to later.

In order to reduce the light of the comparison lamp to about the blueness of sunlight or skylight, as the measurements required, blue-glass screens whose transmission coefficients had been determined by the Bureau of Standards were employed. The Bureau of Standards also determined the transmission coefficients of screens employed to reduce daylight illumination to an intensity comparable with that produced by the comparison lamp. For details relative to these screens reference may be made to an earlier paper by the writer.[1] It may be stated, however, that the combination of screens most frequently used required the factor 490.4 to reduce the readings of the photometer scale to foot-candles of illumination.

Most of the photometric readings were made by the writer; and also on the frequent occasions when the instrument was checked with a standard lamp at the Bureau of Standards he likewise read the photometer.

PHOTOMETRIC READINGS.

In Table I is shown a series of photometer readings obtained on June 30, 1914. The first column gives the sun's hour angle from the meridian at the time the readings were made. The second column gives the altitude of the sun above the horizon at this time. The third column gives the character of the photometric exposure—whether to the entire hemispherical vault of the sky, including that part occupied by the sun, or to the sky alone, with the solar screen between the instrument and the sun. The fourth column shows what absorption screens were employed. The next three columns give the photometric readings, and these are followed by their arithmetical mean. Finally, in column 9 is given the equivalent of the mean readings in foot-candles, followed in the last column by a brief description of the clouds present. Subsequent check readings indicated that on June 30 the illumination intensities of column 9 required to be increased by about 1 per cent.

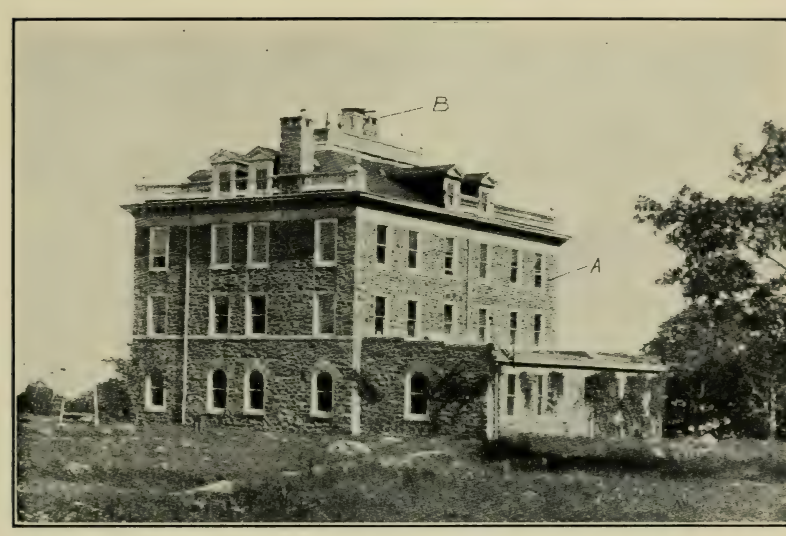

Fig. 1.—Physical laboratory, Mount Weather, Va.

Fig. 2.—Roof exposure.

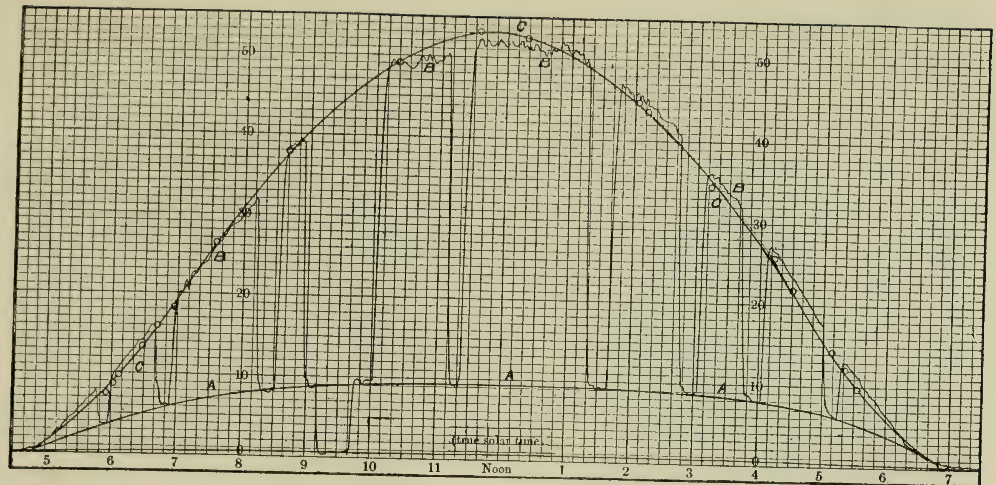

Fig. 3.—Records of solar and sky radiation at Mount Weather, Va., on May 8, 1913.

An examination of Table I shows that individual scale readings rarely differ from the mean by more than 2 per cent. Inaccurate determinations of the constants of the instrument coupled with the personal error of the observer may increase the error of the reduced results, but this error is believed to be less than 5 per cent.

TABLE I.—PHOTOMETRIC READINGS AT MOUNT WEATHER, VA., ON JUNE 30,

Sun's hour angle. A. M. h. m.	Sun's altitude Deg.	Exposure	Screens	Photometric readings. 1	2	3	Mean	Illumination. Foot-candles.	Clouds
5 55	14.3	Sky	VA + *L*	1.50	1.49	1.48	1.49	729	Few ci.
5 52	15.8	Total	VA + *L*	7.25	7.22	7.20	7.22	3,542	Few ci.
4 45	28.5	Sky	VA + *L*	1.58	1.61	1.60	1.60	783	Few ci.
4 11	35.1	Total	VA + *L*	10.2	10.2	10.2	10.2	4,979	Few ci.
2 58	49.1	Sky	VA + *L*	1.79	1.76	1.78	1.78	871	Few ci.
2 55	59.8	Total	VA + *L*	16.5	15.5	16.0	16.0	7,827	Few ci.
1 42	62.2	Sky	VA + *L*	1.88	1.87	1.87	1.87	915	Few ci.
1 38	62.8	Total	VA + *D*	5.80	5.75	5.85	5.80	9,576	Few ci.
0 41	71.9	Sky	VA + *L*	2.00	2.03	2.04	2.02	988	Few ci.
0 37	72.3	Total	VA + *D*	5.95	5.91	6.08	5.98	9,873	Few ci.
P. M.									
0 49	71.1	Sky	VA + *L*	2.15	2.12	2.20	2.16	1,058	1 cu.
0 52	70.7	Total	VA + *D*	5.80	6.00	5.80	5.87	9,691	1 cu.
2 48	51.2	Sky	VA + *L*	2.30	2.31	2.30	2.30	1,126	1 cu.
2 51	50.5	Total	VA + *L*	15.9	15.6	15.8	15.8	7,728	1 cu.
4 48	28.0	Sky	VA + *L*	1.94	1.90	1.92	1.92	939	2 cu.
4 51	27.4	Total	VA + *L*	7.20	7.19	7.30	7.23	3,547	2 cu.

DAYLIGHT ILLUMINATION ON A HORIZONTAL SURFACE.

In Table II are summarized measurements of the illumination of a horizontal surface by daylight, with the sun at different hour angles from the meridian, both before and after noon. The measurements were made on days when but few clouds were present. Besides the decreased illumination with increased hour angle of the sun from the meridian, it is also of interest to note the diminution in the noon illumination in winter as compared with summer. In December, for instance, the noon intensity averaged about 4,300 foot-candles, as compared with 9,600 foot-candles in June. There are also great variations in the noon intensities from day to day. On January 23, for example, the upper atmosphere, while apparently cloudless, was filled with a peculiar white haze, which decreased the intensity of daylight illumination at noon to about 85 per cent. of its average noon value at this season. Again, on May 26, the lower atmosphere

was filled with smoke that decreased the noon daylight intensity to about 75 per cent. of its average value for the season. The measurements for May 26 may be compared with those for June 30, which was an unusually clear day at Mount Weather.

TABLE II.—PHOTOMETRIC MEASUREMENTS OF THE ILLUMINATION OF A HORIZONTAL SURFACE BY SUNLIGHT AND SKYLIGHT, WITH NO CLOUDS PRESENT, AT MOUNT WEATHER, VA.

[Foot-candles.]

Date.	Hour angle of the sun from the meridian.											
	6.0	5.0	4.0	3.0	2.0	1.0	0.0	1.0	2.0	3.0	4.0	5.0
1913.												
Sept. 23	...	1,300	3,040	4,570	6,570	7,350	7,500	7,270	6,400	4,720	2,940	...
24	...	...	2,400	4,140	5,880	6,640	6,810	6,680	6,120	4,330	2,860	...
Oct. 4	...	1,010	2,820	4,510	6,190	7,020	7,290	7,070	...	...	...	...
14	...	...	2,030	4,030	6,110	6,980	6,950	6,680	5,630	4,040	2,120	500
16	...	...	2,080	3,770	5,380	6,390	6,700	6,210	5,090	3,660	1,920	...
Nov. 4	...	...	...	...	...	...	4,670	4,340	3,430	2,160	910	...
5	...	...	1,130	3,080	4,370	5,380	5,630	5,280	4,450	3,150	1,500	...
6	...	...	1,370	2,970	4,560	5,440	5,640	5,360	4,430	3,170	1,450	...
7	...	...	...	2,820	4,350	4,840	5,200	...	...	...	...	...
12	...	...	1,350	2,210	3,750	4,920	5,250	...	...	...	...	...
21	...	...	...	...	3,350	4,200	4,590	4,300	...	...	...	...
Dec. 5	...	...	660	1,900	3,090	3,950	4,300	...	...	...	...	...
9	...	...	...	1,940	3,270	4,030	4,180	3,960	3,140	...	...	...
12	...	...	650	1,930	3,150	3,990	4,320	...	...	...	...	...
18	...	...	490	1,460	2,390	3,430	...	...	...	...	...	...
1914.												
Jan. 6	...	...	...	...	...	...	...	3,890	3,220	1,980	680	...
23	...	...	...	1,460	2,390	3,210	3,610	3,500	...	...	...	...
26	...	...	...	...	...	3,880	4,460	4,430	3,580	2,200	960	...
29	...	...	...	2,330	3,570	4,550	4,720	4,420	...	...	...	...
Feb. 2	...	...	...	...	...	...	5,210	4,810	4,070	2,810	1,210	...
9	...	...	...	...	...	...	5,280	4,980	4,050	2,680	1,370	...
21	...	...	...	...	4,720	6,330	6,680	6,590	6,010	...	...	...
24	...	...	...	...	...	6,130	6,260	6,030	5,280	3,860	1,960	...
May 1	770	2,460	4,280	6,150	...	...	...	...	...	...	...	...
15	...	2,570	4,150	6,340	7,770	8,280	8,390	...	...	...	...	...
16	...	...	4,610	5,760	6,850	7,910	...	...	...	...	...	...
18	...	...	4,330	6,300	7,640	8,200	8,230	7,820	7,100	6,170	4,500	2,890
19	...	...	4,210	6,220	7,790	8,760	...	...	...	...	...	...
20	...	2,000	3,540	5,420	7,360	7,590	7,380	6,690	5,920	5,110	3,200	...
21	...	...	...	...	...	...	...	...	7,150	5,890	4,160	...
26	...	...	...	5,920	6,200	6,430	6,560	6,530	6,300	...	...	...
June 2	...	...	5,080	7,040	8,270	9,020	9,320	...	...	...	...	...
3	...	...	...	...	...	8,620	...	...	...	...	...	...
10	...	...	4,960	6,540	7,990	8,880	9,400	...	...	...	...	...
12	...	...	...	6,740	8,100	...	...	...	...	...	...	...
24	...	3,150	4,810	6,770	8,190	9,270	...	...	...	...	...	...
26	...	...	...	5,900	8,050	...	...	...	...	...	...	...
30	...	3,540	5,350	6,830	9,090	9,900	10,000	9,720	9,060	7,520	5,500	3,210
July 22	1,350	3,250	5,410	6,720	8,470	9,510	...	...	...	...	...	...
29	...	3,350	5,500	7,610	...	...	...	...	...	...	...	...
Aug. 7	...	2,220	3,870	5,660	7,150	8,320	...	...	...	...	...	...
Sept. 10	...	...	...	5,630	6,910	7,620	8,390	...	...	...	...	...
15	...	...	...	...	...	...	...	...	7,180	5,850	3,680	2,240

SKYLIGHT ILLUMINATION.

In Table III are summarized measurements of the illumination of a horizontal surface by skylight alone, direct sunlight being excluded by the use of the screen above referred to. Here again

TABLE III.—PHOTOMETRIC MEASUREMENTS OF THE ILLUMINATION OF A HORIZONTAL SURFACE BY SKYLIGHT ALONE, WITH NO CLOUDS PRESENT, AT MOUNT WEATHER, VA.

[Foot-candles.]

Date	Hour angle of the sun from the meridian											
	6.0	5.0	4.0	3.0	2.0	1.0	0.0	1.0	2.0	3.0	4.0	5.0
1913												
Sept. 23	...	...	785	904	951	988	1,139	1,191	1,173	1,112	...	...
24	...	...	...	1,084	1,388	1,516	1,554	1,534	1,465	1,309	990	...
Oct. 4	...	577	965	1,126	1,180	1,200	1,200	...	...	...	...	...
14	...	...	759	908	1,014	1,093	1,110	1,088	1,017	908	747	...
16	...	...	788	970	1,109	1,193	1,214	1,207	1,142	1,012	823	...
Nov. 4	...	...	...	...	...	...	1,514	1,476	1,340	1,093	686	...
5	...	...	608	837	973	1,033	1,050	1,036	973	834	593	...
6	...	...	684	778	855	903	920	890	840	740	570	...
7	...	...	...	756	944	1,266	1,452	...	...	...	...	...
12	...	...	670	848	985	1,030	1,030	...	...	...	...	...
21	...	...	...	...	1,178	1,276	1,305	1,200	...	...	...	...
Dec. 5	...	...	435	645	753	938	1,100	...	...	...	...	...
9	...	...	...	739	855	928	940	900	808	...	...	...
12	...	...	410	653	778	834	852	...	...	...	...	...
18	...	...	372	815	1,075	1,216	...	...	...	...	...	...
1014												
Jan. 6	...	...	...	...	...	...	...	1,070	924	748	450	...
23	...	...	...	1,344	1,745	1,924	1,950	1,800	...	...	...	...
26	...	...	...	...	...	...	1,277	1,250	1,144	905	580	...
29	...	...	...	780	955	994	1,072	1,080	...	...	...	...
Feb. 2	...	...	...	...	...	...	...	760	760	690	508	...
9	...	...	...	...	...	...	...	900	878	772	540	...
21	...	...	...	...	1,054	1,060	1,060	...	...	...	...	...
24	...	...	...	...	...	...	...	1,220	1,220	1,118	706	...
May. 1	642	1,400	1,800	2,158	...	...	...	...	...	...	...	...
15	...	...	...	2,318	2,568	2,728	2,868	...	...	...	...	...
16	...	...	1,672	1,938	2,092	2,165	2,178	...	...	...	...	...
18	...	...	1,475	1,740	1,875	1,935	1,934	1,885	1,784	1,612	1,370	1,050
19	...	...	1,875	2,028	2,470	2,933	...	...	...	...	...	...
20	...	1,470	2,016	2,355	2,600	2,746	2,818	2,800	2,615	2,100	1,516	...
21	...	...	...	...	...	...	...	...	2,137	1,985	1,720	...
26	...	...	...	...	2,800	2,600	2,500	2,600	2,770	...	...	...
June 2	...	...	980	1,425	1,750	1,480	...	...	...	...	...	...
3	...	...	...	...	...	1,980	1,880	...	...	...	...	...
10	...	...	1,185	1,210	1,360	1,720	2,000	...	...	...	...	...
12	...	...	...	1,190	1,220	...	...	...	...	...	...	...
24	...	830	960	1,080	1,200	1,330	...	...	...	...	...	...
26	...	...	...	1,440	1,580	...	...	...	...	...	...	...
30	...	750	810	870	920	980	1,040	1,050	1,110	1,130	1,050	920
July 22	580	880	1,070	1,210	1,290	1,360	...	...	...	...	...	...
29	...	750	870	970	...	...	...	...	...	...	...	...
Aug. 7	...	1,390	1,900	2,160	2,410	2,750	...	...	...	...	...	...
Sept. 10	...	...	...	780	790	800	820	...	...	...	...	...
15	...	...	...	...	...	...	...	...	890	800	710	640

we note the decrease in illumination with increased hour angle of the sun from the meridian, and also lower noon values in winter than in summer. On January 23, however, the skylight illumination was about twice as great as the mid-winter average, and it was much above the mid-summer average on May 26. In fact, throughout May, which was a month with much smoke, skylight illumination was above the seasonal average, and was about double that for June 30, which, as already stated, was an unusually clear day.

SOLAR ILLUMINATION.

The above data refer to illumination intensities on a horizontal surface. We wish to determine the intensity of solar illumination alone on a surface normal to the direction of the incident solar rays. Subtracting the skylight illumination intensities of Table III from the total daylight intensities of Table II there remains the illumination produced on a horizontal surface by the sun alone. Dividing this by the cosine of the sun's zenith distance at the time of observation we obtain the intensity of illumination on a surface normal to the direction of incidence of the solar rays. If the logarithms of the intensities on any half-day are plotted against the air masses, or approximately the secant of the sun's zenith distance at the time of the observations, they fall very nearly on a straight line, so that interpolation to any desired solar zenith distance may be accurately accomplished. In Table IV are given illumination intensities corresponding to convenient multiples of unit air mass, determined as indicated above. In the heading of the table the corresponding zenith distances of the sun are also given.

For any given solar zenith distance we note the marked variations in solar illumination from day to day. On January 23, for example, already described as a day with dense white haze in the upper atmosphere, with solar zenith distance 60.0° the illumination was only half that of days that preceded and followed, and for zenith distance 70.7° it was only one seventh. During nearly every day in May, with solar zenith distance 48.3° the illumination was considerably below the average, while during most of November, 1913, with solar zenith distance 60°, it was above the average. On account of the annual variations in

TABLE IV.—SOLAR ILLUMINATION ON A SURFACE NORMAL TO THE DIRECTION OF THE INCIDENT SOLAR RAYS.

[Foot-candles.]

Date.	Zenith distance of the sun (degrees)									
	25.0	48.3	60.0	66.5	70.7	73.6	75.7	77.4	78.7	79.8
	Air mass									
	1.1	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5
1913.										
Sept. 23 a	...	7,840	6,850	5,980	...	...	...	...	...	...
24 a	...	6,360	5,730	5,160	...	...	...	...	...	...
Oct. 4 a	...	8,040	6,850	6,020	5,380	4,890	4,470	4,110	3.780	3,480
14 a	...	8,710	7,360	6,240	5.270	4,470	...	...	...	...
16 a	...	8,040	6,740	5,660	4,490	3,570	...	...	...	...
Nov. 4 a	...	6,040	4,630	3,760	2,700	2,100	1,680	1,340	...	...
5 a	...	8,520	7,620	6,690	5,870	5,160	4,520	...	...	...
5 p	...	...	7,570	6,870	6,220	5,640	5,100	4.520	4,190	3,810
6 a	...	...	7,770	6,760	5,890	5,120	4,460	3,880	...	...
6 p	...	...	7,800	7,100	6,320	5.850	5,310	4,830	4,390	3,980
7 a	...	...	7,320	6,500	5,760	...	...	...	...	...
12 a	...	...	7,140	5,930	5,100	4,570	4,300	3.940	...	...
21 a	...	...	5,970	4,830	...	...	...	...	...	...
Dec. 5 a	...	...	7,250	6,370	5,750	4.920	4,330	...	...	...
9 a	...	...	7,420	6,370	5,510	4.920	4,390	...	...	...
9 p	...	...	...	6,460	...	...	...	...	...	...
12 a	...	...	6,650	6,120	5,630	5,180	4,760	4,400	...	...
18 a	...	...	...	3,910	3,250	2,870	2,570	2,320	2,100	1,920
1914.										
Jan. 6 p	...	...	...	6,050	5,520	4,840	4,190	3,770	3,510	3,290
23 a	...	...	3,200	1,610	762	...	...	...	...	...
26 a	...	...	6,270	4,960	4,270	3,820	3,450	3,140	...	...
29 a	...	...	6,300	5,460	4,980	4,590	...	...	...	...
Feb. 2 p	...	...	7,280	6,470	5,940	5,490	5,040	4,610	4,210	3.850
9 p	...	8,150	6,460	5,440	4.900	4,560	4,300	4,050	...	...
24 p	...	7,810	6,460	5,630	5,030	4,560	...	...	...	...
May 1 a	...	5,640	4,960	4,390	3,880	3,450	...	...	...	...
15 a	6,940	5,160	...	...	...	...	...	...	...	...
16 a	6,140	5,520	4,770	...	...	...	...	...	...	...
18 a	6,840	5,520	...	...	...	...	...	...	...	...
18 p	...	6,050	4,810	3,830	...	...	...	...	...	...
19 a	6,180	5,180	...	...	...	...	...	...	...	...
20 a	5,380	3,480	...	...	...	...	...	...	...	...
20 p	...	3,290	...	...	...	...	...	...	...	...
21 p	6,030	5,020	...	...	...	...	...	...	...	...
26 a	6,020	...	...	...	...	...	...	...	...	...
June 2 a	...	7,210	...	...	...	...	...	...	...	...
3 a	6,940	...	...	...	...	...	...	...	...	...
10 a	7,710	5,260	...	...	...	...	...	...	...	...
12 a	8,180	7,000	...	...	...	...	...	...	...	...
24 a	8,350	6,900	5,800	5,130	...	...	...	...	...	...
30 a	9,700	8,250	...	...	...	...	...	...	...	...
30 p	9,180	8,130	...	...	...	...	...	...	...	...
July 22 a	8,870	7,710	6,530	5,610	4,860	4,260	3,790	...	...	...
29 a	...	8,560	6,810	...	...	...	...	...	...	...
Aug. 7 a	6,230	4,230	3,340	2,630	2,100	...	...	...	...	...
Sept. 10 a	...	8,100	...	...	...	...	...	...	...	...
15 p	...	8,630	7,710	6,830	5,970	5,160	...	...	...	...

the earth's solar distance we would expect illumination intensities corresponding to any given zenith distance of the sun to be 7 per cent. higher at the end of December than at the end of June. Table IV shows that in the observations of a single year variations due to atmospheric conditions completely mask variations due to the earth's solar distance.

A comparison of Tables II and IV will show that from September to February, inclusive, at all hours of the day, solar illumination at normal incidence generally exceeds the total daylight illumination on a horizontal surface; but from May to August, inclusive, the illumination on a horizontal surface is in excess from four to eight hours in the middle of the day. In general, the more haze the atmosphere contains the greater and the longer continued is the mid-day excess of the total horizontal illumination over direct solar illumination.

COMPARISONS BETWEEN THE TOTAL AND LUMINOUS RADIATION.

The illumination intensities of Table IV have been compared with synchronous pyrheliometric measurements of the intensity of direct solar radiation (2). These are comparisons of the luminous effect and the heating effect of direct solar radiation. The ratio $\frac{\text{solar illumination in foot-candles.}}{\text{solar radiation in gram–calories per min. per sq. cm.}}$ varies with atmospheric conditions and with the hour of the day, reaching a maximum at midday, and being higher on clear days than on cloudy days. For solar zenith distance 48.3°, its average was found to be 5,600. That is to say, with the sun at this zenith distance a solar radiation intensity of 1 gram-calory per minute per square centimeter corresponds to an illumination intensity of 5,600 foot-candles. For solar zenith distance 66.5° the value is 5,100 foot-candles; and for zenith distance 73.5° it is 4,600 foot-candles.

Comparisons have also been made between measurements by means of the Callendar pyrheliometer of the quantity of heat received on a horizontal surface diffusely from the sky, and synchronous measurements of the illumination of a horizontal surface by skylight alone, such as are summarized in Table III.

In Fig. 3 is shown a record obtained with a Callendar pyrheli-

ometer on a clear day. The irregular trace *BBB* is a record of the diurnal variation in the total radiation received from the sun and sky. The depressions in this trace were produced by interposing the screen already shown at *D,* Fig. 2, between the receive of the pyrheliometer, *A,* and the sun. The curve *AAA* therefore represents the diurnal variation in the quantity of heat received from the sky alone. The smooth curve *CCC* represents the vertical component of solar radiation measurements made with a Marvin pyrheliometer, and plotted from *BBB* as a base, for the purpose of determining the value of the vertical scale of Fig. 3 in heat units. The method has been described elsewhere (3). Comparisons between heat measurements obtained from curves similar to AAA and synchronous photometric measurements of skylight illumination give for one gram-calory of diffuse sky radiation per minute per square centimeter an illumination intensity of 8,900 foot-candles.

Similar comparisons between Callendar records obtained when the sky was overcast and simultaneous photometric readings give for 1 gram-calory of radiation per minute per square centimeter an illumination intensity of 6,250 foot-candles.

All the above comparisons are in accord with facts already established, namely, that the luminous rays in the solar spectrum suffer greater depletion in passing through the earth's atmosphere than do the heat rays, and in consequence when the sun is near the zenith its spectrum is richer in luminous rays than when it is near the horizon; further, radiation from a cloudy sky is somewhat richer, and radiation from a clear sky markedly richer, in luminous rays, than is direct solar radiation.

ILLUMINATION FROM AN OVERCAST SKY.

With an overcast sky the variations in daylight intensity are ordinarily so rapid that photometric measurements have little significance. The illumination may be one half as intense as daylight with a clear sky, and is frequently one third as intense. In general, therefore, the illumination from a cloudy sky exceeds that from a clear blue sky, but this is by no means always the case. Using the factor 6,250 foot-candles per $\frac{\text{gram-calory}}{\text{min.} \times \text{cm}^2}$, in connection with Callendar records, it is found that at noon in

winter at Mount Weather with a dense fog the illumination on a horizontal surface sometimes falls to 168 foot-candles, and at noon in summer during a severe thunderstorm it once fell to 85 foot-candles.

EFFECT OF CITY SMOKE ON DAYLIGHT.

Daylight illumination is ordinarily ample for out-door occupations, such as farming and transportation, from sunrise to sunset. In the country even in a dense fog there is sufficient daylight to enable one to read, except when the sun is near the horizon, but the limit of vision is greatly restricted by the translucent character of the fog. Hence, in the country the chief inconvenience experienced from diminished daylight intensity during fogs arises from the lessened number of effective hours of daylight. The same may also be said of a dense cloud layer.

When smoke becomes mixed with a fog or cloud layer it may render it nearly opaque, so that daylight even at mid-day is inadequate for out-door occupations. Indoors, daylight or natural illumination is frequently barely sufficient under the most favorable sky conditions. The inconvenience arising from the effects of fog or clouds or smoke is therefore here many times magnified.

The Weather Bureau is now measuring daylight intensities at different points in Salt Lake City, Utah. Some of these points are under the smoke cloud that frequently envelops the city, especially in the early morning or late afternoon. Others are in the suburbs outside the smoke cloud. It is expected that a summary of these measurements will be received in season to be presented in connection with the discussion of this paper. It may be said in general, however, that they confirm chemical determinations, made at various places, in showing a diminution in daylight intensities by the city smoke cloud of from 15 to 40 per cent (4). Furthermore, this diminution in daylight intensity is especially serious because it is at its maximum at about sunrise, and frequently with a secondary maximum about sunset, or at just the times when even in country districts there is no excess of illumination. Under favorable conditions, therefore, city smoke shortens the hours of effective daylight, and under the worst conditions may practically eliminate them.

Reference may also be made to the increased frequency of fogs

in the presence of smoke. At Salt Lake City (5), for example, previous to 1902, the year when most of the smelters commenced operations, the Weather Bureau records show that there had been 25 foggy days in 11 years; while in the 11 following years there were 221 foggy days, or nearly a nine-fold increase. This increased frequency, and likewise the greater persistency of fogs in the presence of smoke, must be taken into account in considering the effect of smoke upon daylight illumination (4).

DURATION OF TWILIGHT.

By twilight we mean the light which is experienced after sunset and before sunrise, and which is due to the reflection, diffraction, or diffusion of sunlight by the gas molecules, the water particles, and the dust of the atmosphere. The greater the distance of the sun below the horizon the higher and less dense are the atmospheric layers from which the light is received at the shaded surface of the earth. Observation has shown that under the most favorable atmospheric conditions the last trace of twilight disappears when the sun is from 16° to 18° below the horizon, indicating that above a height of 40 to 50 miles, or 60 to 80 kilometers, the air is too rare to reflect or diffuse an appreciable amount of sunlight.

The duration of twilight may be computed from the equation: $\cos h = \frac{\sin a - \sin \phi \sin \delta}{\cos \phi \cos \delta}$, where a is the sun's altitude, considered minus below the horizon, δ is the solar declination, or distance from the celestial equator, ϕ is the latitude of the place of observation, and h is the sun's hour angle from the meridan.

From the above equation it will be found that at the equator, at the time of the equinoxes, when the apparent path of the sun is along the prime vertical, it takes the sun 1 hour and 12 minutes to pass from the horizon to a point 18° below it, or vice versa. At the solstices, when the sun appears to describe a small circle about the earth's axis 23½° from the prime vertical, the time is 1 hour and 19 minutes. At latitude 49°, or the latitude of the northern boundary of the United States, where the sun's apparent path is inclined 49° to the plane of the prime vertical, at the equinoxes it takes 1 hour and 52 minutes for the sun to pass from the horizon to a point 18° below. At the time of the winter

solstice it takes 2 hours and 3 minutes, while at the time of the summer solstice the sun does not reach 18° below the horizon. In fact, there is a period of twenty-two days, from June 10th to July 2nd, inclusive, during which on the clearest nights the twilight may continue from sunset to sunrise.

Soon after sunset on very clear evenings there frequently appears in the western sky a rosy or purple glow, in the form of an arc about 20° to 25° in diameter with the sun at its center. It disappears when the sun is about 6° below the horizon, indicating that it comes from atmospheric layers not more than 5 or 6 miles, or 8 to 10 kilometers above the surface of the earth. It is in these layers that convective action principally occurs, and they are therefore the dusty layers, as well as the layers that contain most of the atmospheric moisture. The purple glow is attributed to the diffraction of light by the dust and water particles in these layers. During the day the same process produces the whitish glow that is seen about the sun in clear weather.

With the disappearance of this glow the intensity of twilight becomes insufficient for the continuance of out-door occupations. Hence, it is the duration of this portion of the twilight, which Europeans term *civil twilight* that is of practical interest, and especially to those engaged in pursuits having to do with transportation, or any other line of out-door work that requires artificial lighting after nightfall, either for illumination or for signal purposes.

The intensity of twilight is not entirely dependent upon the position of the sun, however. The state of the sky is a modifying factor. Clouds on the western horizon, or a hazy condition of the atmosphere that may be due to either dust or moisture, noticeably diminish the twilight intensity, and in the case of very dense clouds may almost completely obliterate it. It is believed, however, that Table V, which gives the duration of civil twilight, or the time required for the sun to pass from the horizon to a point 6° below or vice versa, will be found useful to Weather Bureau officials and others. But it must be understood that the duration as given applies to clear sky conditions only, and is too long for cloudy or hazy conditions. Furthermore, high mountains and buildings, or any objects that obstruct the horizon near where the sun rises or sets, will diminish the duration of twilight. It will

be noted that at the equator civil twilight only varies in duration from 24 minutes at the equinoxes to 26 minutes at the solstices, while at latitude 48°, near the northern boundary of the United States it varies in duration from 36 minutes at the equinoxes to 43 minutes at the winter solstice and 48 minutes at the summer solstice. At Cleveland the variation is from 32 minutes at the equinoxes to 37 minutes at the winter solstice and 39 minutes at the summer solstice.

TABLE V.—DURATION OF CIVIL TWILIGHT. (TIME REQUIRED FOR THE SUN TO PASS FROM THE HORIZON TO A POINT 6° BELOW, OR VICE VERSA.)

North Latitude (Degrees.)

Date	0°	10°	20°	25°	30°	32°	34°	36°	38°	40°	42°	44°	46°	48°	50°
	Minutes														
Jan. 1	26	26	28	29	31	31	32	33	34	35	37	38	40	42	45
11	26	26	28	29	30	31	32	33	34	35	36	38	39	41	44
21	26	26	27	28	30	30	31	32	33	34	35	37	38	40	43
Feb. 1	25	25	27	28	29	30	31	31	32	33	34	36	37	39	41
11	25	25	26	27	29	30	30	31	32	33	34	35	36	38	39
21	24	25	26	27	28	29	29	30	31	32	33	34	35	37	38
Mar. 1	24	25	26	27	28	28	29	30	31	32	33	34	35	36	38
11	24	24	26	27	28	28	29	30	30	31	32	34	35	36	37
21	24	24	26	27	28	28	29	30	30	31	32	33	35	36	38
Apr. 1	24	24	26	27	28	29	29	30	31	32	33	34	35	37	38
11	24	25	26	27	28	29	30	30	31	32	33	34	36	37	39
21	25	25	26	27	29	29	30	31	32	33	34	35	37	39	41
May 1	25	25	27	28	29	30	31	32	33	34	35	37	38	40	42
11	25	26	27	28	30	31	32	33	34	35	36	38	40	42	45
21	26	26	28	29	31	32	32	34	35	36	38	40	41	44	47
June 1	26	26	28	29	31	32	33	34	36	37	39	41	43	46	49
11	26	27	28	30	32	32	34	35	36	38	39	42	44	47	51
21	26	27	29	30	32	33	34	35	36	38	39	42	44	48	51
July 1	26	27	28	30	32	32	34	35	36	38	39	42	44	47	51
11	26	26	28	29	31	32	33	34	36	37	39	41	43	46	49
21	26	26	28	29	31	32	33	34	35	36	38	40	41	44	47
Aug. 1	25	26	27	28	30	31	32	33	34	35	36	38	40	42	45
11	25	25	27	28	29	30	31	32	33	34	35	37	38	40	42
21	25	25	26	27	29	29	30	31	32	33	34	35	37	39	41
Sept. 1	24	25	26	27	28	29	30	30	31	32	33	34	36	37	39
11	24	24	26	27	28	29	29	30	31	32	32	34	35	36	38
21	24	24	26	27	28	28	29	30	31	31	32	33	35	36	38
Oct. 1	24	24	26	27	28	28	29	30	30	31	32	34	35	36	37
11	24	25	26	27	28	28	29	30	31	32	33	34	35	36	38
21	24	25	26	27	28	29	29	30	31	32	33	34	35	37	38
Nov. 1	25	25	26	27	29	29	30	31	32	33	34	35	36	38	40
11	25	26	27	28	29	30	31	32	32	34	35	36	37	39	41
21	26	26	27	28	30	30	31	32	33	34	35	37	38	40	43
Dec. 1	26	26	28	29	30	31	32	33	34	35	36	38	40	41	44
11	26	26	28	29	31	31	32	33	34	35	37	38	40	42	45
21	26	27	28	29	31	31	33	33	34	36	37	39	40	43	45

Table V gives the difference between the time when the center of the sun reaches the true horizon and the time it reaches a point 6° below, or vice versa. Without material error, we may add this interval to the time of sunset given in the Weather Bureau Sunshine Tables, or subtract it from the time of sunrise, to obtain the time of ending of civil twilight in the evening or its beginning in the morning. The time thus determined will be that at which the upper limb of the sun is 6° lower than it was at the time it appeared to rise or set on a true horizon, assuming normal atmospheric refraction, and mean solar diameter.

TABLE VI.—PHOTOMETRIC MEASUREMENTS OF DAYLIGHT AND TWILIGHT ILLUMINATION AT MOUNT WEATHER, VIRGINIA, ON A SURFACE EXPOSED HORIZONTALLY, AND AT SALT LAKE CITY, UTAH, ON A SURFACE NORMAL ALTERNATELY TO THE ZENITH AND THE WESTERN HORIZON.

Mount Weather, Virginia.									Salt Lake City, Utah.		
Nov. 4, 1913. (1)			Nov. 5, 1913. (2)			Nov. 6, 1913. (3)			Dec. 15, 1914. (4)		
Sun's			Sun's			Sun's			Sun's		
Hour Angle	Altitude	I	Hour Angle	Altitude	I	Hour Angle	Altitude	I	Hour Angle	Altitude	I
H. m.	°		H. m.	°		H. m.	°		H. m.	°	
			4:53	+2.6	242	4:49	+3.1	279	†4:19	+2.8	
			5.00	+1.3	170	4:58	+1.5	172	4:22	+1.6	206 (5)
5:05	+0.6	90							4:25	+1.1	87 (6)
*5:08	±0,0		*5:07	±0.0		*5:06	±0.0	98	*4:37	±0.0	
5:12	—0.6	37	†5:11	—0.6		†5:10	—0.7		4:41	—0.6	42 (5)
5:20	—1.9	13	5:15	—1.4	57	5:17	—2.0	27	4:44	—1.1	20 (6)
			5:23	—2.9	14	5:29	—4.2	3	5:01	—4.0	1.6 (5)
									5:06	—4.8	0.4 (6)
						5:38	—5.9	0.4	5:12	—5.2	0.12 (5)
									5:14	—6.2	0.07 (6)

I = Illumination in foot-candles.

* Computed time center of sun's disk was on true horizon, disregarding atmospheric refraction.

† Time of observed sunset.

(1) Nov. 4, 1913. Dense hase. Sun disappeared at sunset in bank of haze.

(2) Nov. 5, 1913. Brilliant sunset. Yellow sky with pink glow above, followed by dull red.

(3) Nov. 6, 1913. Brilliant yellow sunset followed by pink and red.

(4) Dec. 15, 1914. Sunset clear behind Oquirrh Mountains, which are about 2,000 feet above the valley,

(5) Photometric surface normal to western horizon.

(6) Photometric surface normal to zenith.

In Table VI are given photometric measurements of the intensity of twilight with the sun at different distances from the

horizon, made by me at Mount Weather, Va., and by Mr. A. H. Thiessen at Salt Lake City, Utah. They show that on clear days with the sun 6° below the horizon the twilight is less than 1 per cent. as intense as it is immediately after sunset; or, the illumination is approximately that produced by a standard candle at a distance of 3 ft., namely, 0.1 foot-candle, as compared with 10,000 foot-candles at noon on a bright summer day. And yet, on November 6, 1913, I was able to read a graduated circle to tenths of degrees until the sun was nearly 7° below the horizon, by holding the instrument normal to the bright western sky.

REFERENCES.

1. Kimball, Herbert H. Photometric measurements of daylight illumination on a horizontal surface at Mount Weather, Va. Monthly Weather Review, Dec., 1914, vol. 42, pp. 650-653.
2. Note.—The pyrheliometer readings are summarized in the Bull. Mt. Weather Observatory, 1913, vol. 6, pp. 215-219, and in the Monthly Weather Review, 1914, vol. 42, pp. 139, 310, 520.
3. Kimball, Herbert H. The total radiation received on a horizontal surface from the sun and sky at Mount Weather, Va. Monthly Weather Review, Aug., 1914, vol. 42, pp. 474-480.
4. Note.—For a fuller discussion of this subject, with references to other works, see my paper on "The Meteorological Aspect of the Smoke Problem." Monthly Weather Review, Jan., 1914, vol. 42, pp. 29-35, or Smoke Investigation Bulletin No. 5, Mellon Institute of Industrial Research and School of Specific Industries, University of Pittsburgh.
5. Alter, J. Cecil. "Who Taught Salt Lake City to Smoke?" Mines and Methods, Jan., 1913, vol. 4, pp. 105-109.

THE PROJECTING LANTERN.*

BY JOHN B. TAYLOR.

Synopsis: The paper outlines the principles, development and operation of the projection lantern. The requirements of screens and the physiological aspects of vision are also discussed.

Such consideration as can be given to the projecting lantern in part of an evening meeting must of necessity be brief and, in parts, disconnected. Books on the subject run to several hundred pages and I admit the omission of consideration of some phases on the subject. In fact a number of treatises might be written without exhausting the field, for its different aspects include everything that the illuminating engineer may meet in any of his activities. Engineering (mechanical and electrical), chemistry, physics, optics, physiology and psychology—all these sciences are essential and each contribute its part in a greater or less degree. When all these divisions have been considered there still remains the artistic side, which is perhaps less tangible but quite as important.

The "magic-lantern" and the "magic-lantern exhibition," to select from the great confusion of names all relating to the same thing, has reached the stage where no home, school, church, theater or public gathering place of any kind is complete without one. In these places it serves for education, entertainment and as an aid to the world's business activities.

Educational uses of the lantern have changed from first to second place in the few years since the cinematograph exhibition

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or now familiar "movie," with its ramifications, has come to be such an enormous industry. There is an old bit of philosophy to the effect that a nation is moulded and influenced more by its songs than by its laws. This I may parody by saying,—Let me produce the "movies" of a nation and I care not who makes its laws. It is to be regretted that of the miles of film pictures shown daily, those devoted to instructing, educating and inspiring may be measured in feet.

Reference has just been made to the confusion of names for the apparatus which produces an enlarged image of a picture or object on a screen. The term "magic-lantern" was quite appropriate so long as the uses were mainly for mystifying and entertaining. The lantern was well developed before the art of photography. The apparent desire to eliminate the word "magic" after the apparatus was put to serious uses brought forth a number of terms[1] of which the poorest seems to have taken the deepest root. The misused term is "stereopticon."[2] There is nothing "stereoscopic" about it. The word "sciopticon" is now seldom used in this country, though it was well known some years ago and might well have been retained. "Projecting lantern," which term I use myself, is not the most desirable as it should apply more properly to searchlights and apparatus for galvanometers, oscillographs and the like. Some inaccuracies and much confusion would be avoided by designating the apparatus as a "picture lantern" and the finished product as a "lantern picture." The terms are simple, shorter than many, accurate and sufficiently broad to cover all forms, whether adapted for transparent or opaque objects, vertical, horizontal or microscopic, separately or in any combination.

At present probably over 99 per cent. of lantern picture work is done with transparent photographic slides or films. As developed and practically standardized, the elements are the source

[1] Photo-electric lantern, solar lantern, stereopticon, sciopticon, diascope, episcope, epidiascope, megascope, aphgenscope, polyopticon, projecting lantern, dissolving lantern, projectoscope, radiopticon, balopticon, delineascope various "scopes" preceded by proper names, etc., not to mention any of the moving picture apparatus.

[2] Properly a "stereopticon" has to do with a pair of pictures taken from a slightly different view-point. Various devices may be used to present one of this pair to the right eye and the other to the left eye. The resulting appearance of relief or solidity is striking, but the added expense, complication and need for use by audience of special viewing devices have prevented any widespread use of such a properly called "stereopticon."

of *light* (or radiant), the collecting and *condensing lens* (or system of lenses or reflectors), the *objective* (system of lenses forming the image of the slide) and the *housing* to confine stray light from the radiant. Whoever first added the condenser put the lantern essentially into its present form.

The first beginnings of the art must go to pre-historic times with shadow pictures on cave walls and ceiling with fire or pine torch as sources of light. The shadow pictures were followed by inverted images in a crude "camera obscura," a light-tight box with a small hole serving in place of the later lens. As soon as a lens was added to take the place of the pin-hole, a *camera* was available and photography awaited only the light sensitive plate. Inverting the *camera obscura* by enclosing the light source and object resulted in the "opaque projector." Many forms of this under various names have recently come on the market.

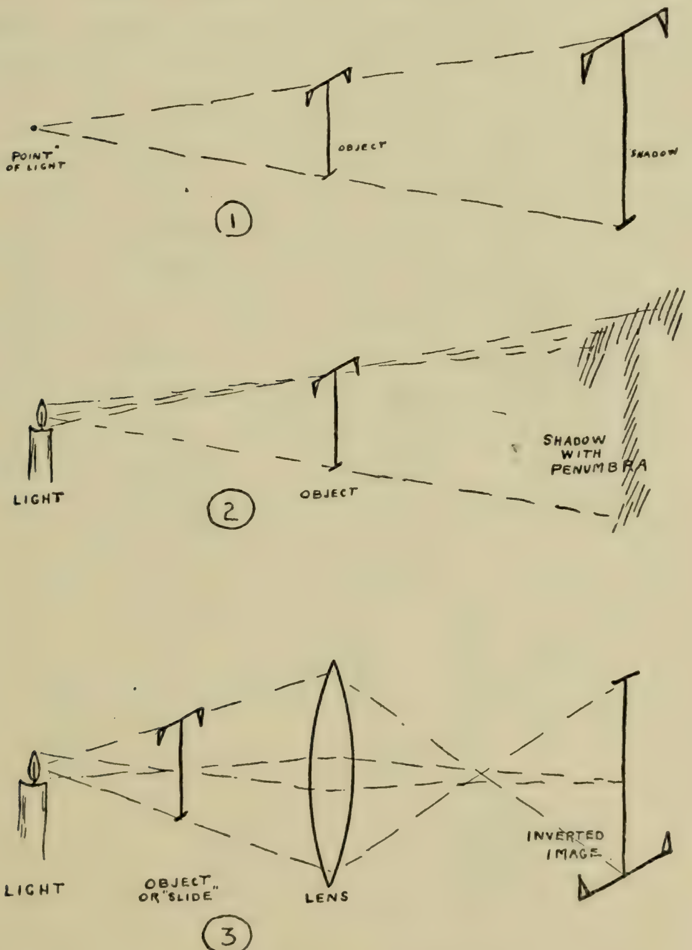
The picture lantern for opaque work is simpler than the lantern for transparencies as the condenser may be omitted. Unless a translucent screen is used, with a lantern on one side and observers on the other sides, the image of the picture is reversed. For serious work and whenever there is reading matter, a mirror to correct this reversal is an essential. Compared with the lantern for transparencies, the condenser may be dropped and a mirror should be added.

The enlarged picture on the screen from a slide may be regarded as a shadow picture in which the condenser is the source of light of such a nature that each part of its surface radiates light in only one direction. These directions being symmetrical about an axis, there is produced a shadow on the screen of the picture on the slide, which is inverted; *i. e.,* top becomes bottom and right becomes left. If the light could be the overworked, hypothetical "point-source," and a well corrected lens system used as a condenser, the objective could be omitted.

A series of diagrammatic projection lanterns for transparent slides, proceeding from the simple shadow picture to the present standard arrangement, is shown in Figs. 1 to 7.

Fig. 1 illustrates the ideal shadow picture with a "point-source" of light. Here the size of screen picture may be made as large

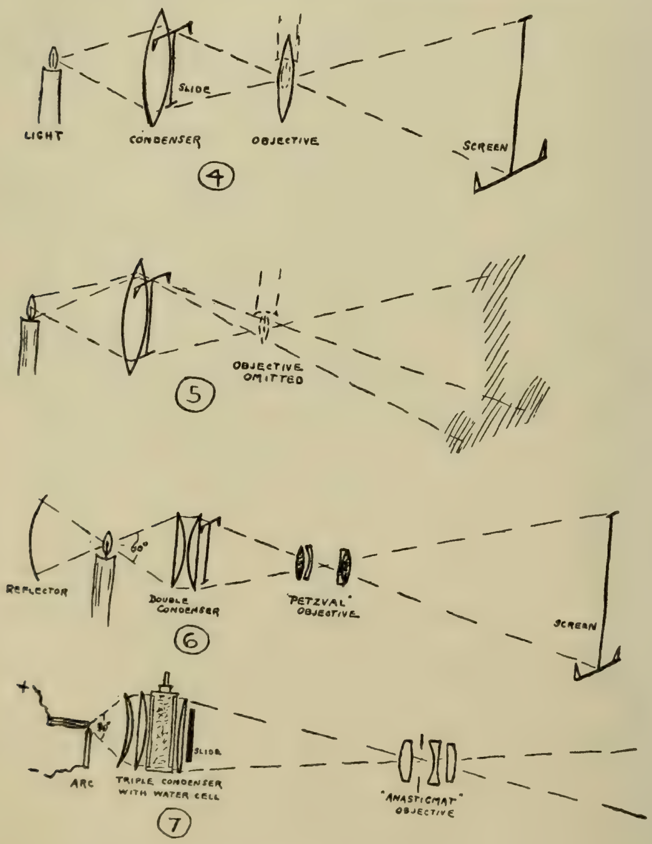
or small as desired by regulating the distance between slide and the "point-source."



Figs. 1, 2 and 3.—Projection diagrams.

Fig. 2 illustrates the practical shadow picture in which the light or radiant has appreciable dimensions and must be sufficiently removed from the slide (or other object) to prevent heat damage. The lines of the screen picture are bordered with a penumbra—details cannot be shown sharply.

In Fig. 3 a lens has been added which occupies a definite position between the object and the screen. The penumbra is eliminated since the lens redirects the diverging radiation, *i. e.*, the slide and screen are conjugate focal planes of the lens. Neglecting aberrations, the screen picture may be sharp; fine details may



Figs. 4, 5, 6 and 7.—Projection diagrams.

be shown. Unless the light source is an extended surface, the objective must be larger than the slide. This leads to a lens of almost impossible dimensions if the radiant is close to the slide (which is as it should be for efficient utilization of the light) and if the lens is a foot or two removed from the slide (which it must be to give a picture of not too great a size on the screen). Note

also the inversion between the slide and the screen. This form of projection is used with the microscope where the small size of the object and the short distance to objective do not require lenses of impossible sizes.

Fig. 4 shows the addition of a condensing lens. This may be regarded as an extended light source—larger than the slide and close to it without burning it up—which permits the objective lens to be of reasonable dimensions. The radiant and objective are conjugate on the condenser. Thus the objective need be no larger than the image of the radiant which in practise is magnified two to six diameters. Besides thus directing the light into an objective lens of moderate dimensions, the condenser incidentally forms a fire-proof wall between the radiant and the slide. This is of greater importance in moving picture projection and microscopic work when the arc or other radiant would have to be extremely close to film or specimen in order to utilize any considerable flux of light.

Fig. 5. In a properly adjusted lantern using a carbon arc the objective may be removed entirely and still leave a recognizable screen picture of the same size and position. The hazy outlines result from size of light source and uncorrected condenser aberrations.

Fig. 6 is somewhat similar to Fig. 4. The condenser is made up of two pieces of glass mounted with convex surfaces inside and plane surfaces outside, which combination gives less serious aberrations than an equivalent single lens which must have great thickness. The most common objective if not taken directly from a portrait camera has been fashioned after the classical Petzval combination. This lens has a large aperture and covers satisfactorily the relatively small lantern slides. This type of lens became firmly established as a projecting lantern objective at the time when kerosene lamps with two or more large wicks were common sources of light. As the flame from such a lamp is partly transparent, a reflector as indicated increased the flux of light in the direction of the condenser. A large aperture objective was essential to utilize efficiently the large light source. On the camera these lenses were designated as one-quarter size, one-half size and full size, as applying to the size of the photo-

graphic plate. These objectionable terms, instead of essential information as to an equivalent focus and size of aperture, have long been given to the public by lens and lantern makers. Even after the extensive use of smaller and more brilliant sources of light have made possible the use of smaller and better corrected lens, the descriptive literature and lenses themselves are put out with no indication of optical length or breadth.

Fig. 7 is a typical diagram of the modern lantern. The source of light is a carbon arc. The condenser may be divided into two or three elements as here shown. With the three elements, the relatively thin meniscus of lesser diameter can be placed close enough to the arc to use an appreciably greater flux of light. The water-cell for absorbing much of the undesirable infra-red radiation is an essential part of every up-to-date lantern. It should be located between the condenser elements where the light flux is approximately parallel. The water-cell will be further considered a little later. The objective should be a well corrected lens of moderately large aperture. The modern photographic "anastigmats" are excellent, though expensive and often better than other parts of the apparatus and condition of operation justify.

The lantern for opaque cards, etc., is made to appeal strongly to the amateur in advertising literature. The results are frequently disappointing. The photograph, picture, drawing, page of book or other object is brightly illuminated. Of the light reflected from the object a small portion only is directed towards the objective. Occasionally specular reflection from parts of the object strike the lens and give extremely bright spots making a disagreeable contrast with the darker portions. Two or more light sources or a divided beam is often the arrangement to reduce deep shadows of solid objects and to generally equalize contrasts. The lenses should be well corrected and of the largest possible aperture. This condition reduces the depth of focus making the screen picture liable to blurring in parts. The large aperture requirement makes proper objectives very costly and therefore a lens of only moderate focal length is supplied or selected. The shorter focus means a larger screen picture with still further reduction in brightness. The opaque lantern must therefore be

set closer to the screen in a position which is not always satisfactory. If provision is made for transparent slides in the same piece of apparatus a separate projection lens of even less focal length is provided so that the picture from the relatively small slide will appear at least as large as the opaque picture. (The slide picture should properly be larger.)

The short focus lens with a lantern close to screen is not the best arrangement for reasons other than convenience of location.

In selecting a lantern equipment for any situation there are several interlocking factors. The screen position must be selected and the size of picture determined. Extremes in distances from observers should be avoided by placing a screen well back on the stage, or by removing some of the front rows of seats. The screen shoud be low to avoid discomfort from looking up.

The lantern should be back of the audience and as nearly as may be on a level with the center of screen. Unless the optic axis of the lantern is perpendicular to the screen, a distorted picture appears on the screen.

The screen should preferably be vertical, but a slight angle is permissible when the lantern cannot be placed on the proper level. A screen too much off the vertical is just as objectionable as a distorted picture.

Other things remaining the same, a smaller picture is brighter and unless carried too far, the greater brightness compensates in a measure for the reduction in size of details. The smaller picture appears better from the front rows; its center is lower requiring less tilting of the lantern and therefore less distortion of the picture.

The further the lantern can be moved back, the less the need of tilting and the less distortion. Long focus lenses are therefore indicated as generally desirable. A 6-in. e. f. lens has been supplied as a matter of course with many cheap and moderate priced lanterns, unless the purchaser is experienced and demands a lens better adapted to general conditions. The justification for this lens giving a large picture with the lantern up front, passed with the waning of the kerosene lamp. If all the 6-in. objectives put out could be replaced with 10-in. objectives, and all those of 10-in. replaced with 18-in., more satisfactory demonstrations would result.

With the size of the picture and the lantern distance fixed, the focal length of objective is determined. This in turn determines the proper focal length for that element of the condenser next to the slide. The focal length of the condenser element towards the radiant determines the flux of light that is utilized. The diameter of the condensing lenses should be ample to cover the slide without showing colored fringes or reduced illumination in the corners.

Theoretically a large radiant like the kerosene burner requires a greater diameter of condenser than does the carbon arc.

After the objective is placed in the position to focus the slide on the screen, the radiant is moved to the position which focuses its image in the center of the objective. It should be noted that changing the position of the radiant at the same time changes the light flux entering the system and passing through the condenser, slide, objective and on to screen. A change in objective to one of quite different focal length should be accompanied by a corresponding change of front element of condenser, so that the radiant may remain in its proper position.

Many expert operators and even some lantern manufacturers will argue that a more powerful light is needed to "throw" a picture from a properly designed and adjusted lantern 40 ft. away than is needed for the same size pciture with a proper lantern 20 ft. away—as though the light became "tired" along the way.

In both cases the same flux of light is passed by the slide, directed toward the screen and spread over the same area. Unless the room is full of smoke, absorption of light in these distances is negligible. A demonstration with two pictures side by side or photometric readings on the two pictures should (but does not always) end the argument.

Nearly all the illuminants from the tallow candle to sunlight have served in lantern picture service; various forms of oil, gas, and electric lights have been adapted. When electric energy is available, the carbon arc holds the field. The electric incandescent is widely used when a moderate amount of light is sufficient, as it has so many advantages. Where there is no current, the oxy-hydrogen lime light (calcium light, or Drummond light) has long

been preeminent. Also for small pictures or where great brilliancy is not necessary, acetylene serves well in the absence of electricity.

In appraising an old or possible new illuminant, the following points should be considered: total light flux; light flux in useful direction; possibility of using reflector; "point-source" (size of radiant and intrinsic brilliancy); color; efficiency (undesirable heat production); ventilation required; ease of starting; steadiness of operation; quietness of operation; expense of operation; expense of replacements; life, reliability, fragility; safety; skill required to adjust and operate; bulk and weight; initial cost.

In this age of "regulation" it is surprising that legislatures, commissioners and censors have not meddled more with the requirements as to "minimum candlepower in the movies" etc.

Lantern slides are frequently shown with satisfaction where the illumination is ½ foot-candle or less in the clear whites of the pictures. On other occasions the reading may be found to be ten to twenty times as great. For moving pictures a brighter screen picture seems desirable, though in those cases where the same lamp is used for moving pictures and for regular lantern slides, the slides will be about twice as bright unless the current is cut down or some absorbing screen interposed.

Many different surfaces and fabrics have been used as screens. Of those which should be opaque, some transmit and waste quite as much light as they reflect. Aluminum painted or other metal surfaced screens show the picture by light which is largely specularly reflected. These appear brilliant to the observer in a favorable position, but viewed from the side there is great unevenness. Photometric measurements may show as great variation as 5 or 10 to 1 and this condition is aggravated with the use of a short focus, wide angle objective. Under extreme conditions the side of a picture away from the observer may appear almost black. Such conditions are most common with translucent screens. The necessity for viewing the ground glass of a photographic camera nearly in the direction in which light is proceeding after leaving the lens is familiar to many. While the special translucent screens distribute better than the common ground glass ones,

those demonstrations in which the lantern and spectators are on opposite sides of the screen are especially liable to uneven pictures. Apart from the greater straight line transmission inherent in the screen, the available space back of the screen usually calls for short focus lenses and the wide angle between the extreme ray on one side and line of vision of observer on the other side explains the many unsatisfactory results.

Familiarity breeds contempt and more was expected of the lantern operator in the days when oxy-hydrogen lime lights in double or even triple lanterns were the order of the day at pretentious demonstrations or lectures. The pictures were skilfully dissolved; many ingenious mechanical slides were devised; the second and third lantern aided in producing special effects like sunrise and sunset, moonrise, lightning, rain, snow, etc. Experiments and demonstrations in chemistry and physics were shown enlarged on the screen; thermometers, galvanometers, etc., were specially constructed to fit the lantern.

The spectacular element is not overlooked in the popular moving pictures, but little seems to have been done lately in producing new experimental devices adapted for projecting. Even the older well worked out devices are frequently overlooked.

The water-cell has been referred to. Through omission of this or an equivalent heat absorbing device many valuable slides are ruined. Color slides of the autochrome variety are sensitive to heat on account of the varnish softening. Hand colored slides are more liable to fade through excessive heating. Microscopic slides and larger slides mounted after the same manner with balsams are easily damaged by overheating. Even the ordinary slides are frequently cracked or otherwise damaged by too rapid evaporation of moisture enclosed. The water-cell is admittedly an added care. Unless the water has been freed from air by boiling, bubbles appear which may show on the screen. The cells do not hold enough water to go through a usual exhibition without boiling. This means delay in changing cells or replacing water. However, until light is obtained efficiently with little or no heat, or other arrangements are devised for disposing of it, the water-cell is an essential of the complete lantern. The old idea that a solution of alum is better than plain clean water is a mistaken notion.

The standard size of slide in this country is 3¼ by 4 in. outside. The binding and mat reduce the actual picture size to about 2¾ in. high by 3 in. wide. There is thus considerable space at each side for labelling with data and names. How far this compensates for extra space and weight over the standard English slide of 3¼ in. square is a question. Though there is little excuse for the display of slides reversed, inverted, or reversed and inverted, such are frequently seen. The English slide may be shown in eight different positions of which but one is right.

As a collection of slides is likely to come from many different sources and be handled by many different lantern operators, it is desirable that there should be standards for marking and arranging. The "spot" in the lower left hand corner to prevent inversion and reversal has come to be quite generally recognized. But it is quite as important to tell at a glance if all the slides in a pile or in a case are right side up, etc. This can be readily done by suitable binding or labelling. It is also desirable that titles or data, and name of maker or owner should appear in standard positions. Further a box of slides handed to a lantern operator should carry some indication of the proper order of showing. Frequently the last is shown first.

Most makers of slides are only too glad to follow the standard so far as they can be satisfied that it is standard. It might be desirable for the Illuminating Engineering Society through its proper officers to look into this and perhaps other projection lantern and moving picture questions. If any recommendations towards standardizatioin appeared in order, this Society would be heard with more weight than some other organizations.

The physiology of vision has an important bearing in connection with lantern pictures. This is frequently overlooked. The eye is many thousand times as sensitive after a period of darkness as at noon on a bright summer day. Astronomers, microscopists, photographers, and X-ray workers recognize this and frequently must wait a number of minutes in almost darkness for the eye to attain the sensitive state (sometimes called "twilight vision") before being able to proceed with the work in hand. In passing from the street with the glare of the sun from the pavement to the interior of a moving picture theater, although

the click of the machine is heard, one may have difficulty in locating the screen at once. Until a whole reel has been shown the pictures will be pronounced very dim.

Besides this delay in acquiring visual sensibility other factors affecting the appearance of a picture are overlooked. The room is often only partly darkened; bright spots around doors and windows may be in the line of vision; the projecting lantern may be in the middle of the "audience"; bright spots often appear on walls, floor or ceiling due to poorly designed ventilating openings in the lamp housing; perhaps there is no bellows or tube connecting the slide with the objective, in which case those who are back of the lantern suffer through having on the retina a bright spot from the back lens of the objective; also there may be appreciable illumination by scattered radiation from the unenclosed slide. An effort should be made to avoid marked contrast in slides.

Autochrome slides transmit about 10 per cent. as much light as ordinary slides. If common slides and the color slides are mixed, it is highly desirable to reduce the illumination for the common ones by cutting down the light or interposing diffusing or absorbing screens. A piece of ground glass between condenser and slide may be found about right. If the lens has an iris diaphragm this may be partly closed.

Some unsuccessful exhibitions of lantern slide color pictures on analysis show some or all of the following points overlooked; room not properly darkened; insufficient time for visual accommodation; lantern leaks light; screen not opaque; picture too large; slides too dense though satisfactory for viewing by hand; source of light insufficient or too yellow in color.

A careful lantern operator will never subject the spectators to the full light of the lantern on the screen without a slide in position. Many lanterns have no means for cutting off the light, except by a loose cap for the objective. This is usually lost or misplaced. A hanging cover is desirable for mechanical protection as well as for a light shield. An iris diaphragm in the lens (so constructed as to close completely which the camera lens iris does not) is a desirable arrangement.

As to focusing, where possible this should be carefully done

before the meeting and left untouched while showing the slides. The operator is usually too far from screen to see details as well as others can and his eyes are likely to be dazzled by adjusting the light, etc. If he has an opera glass he can do better.

Time and space are lacking to do more than refer to moving picture lanterns. Optically these differ from the lantern slide arrangement in the distance between the condenser and the film. The lantern slide is close to the condenser where the illumination is uniform more or less irrespective of shape and size of the light source. The moving film has a position approaching the enlarged image of the light source. The shape, size and evenness of this therefore, become of importance and the aberrations of the condensing lenses may even be advantageous in blurring over and equalizing illumination.

DISCUSSION.

MR. F. L. G. KOLLMORGEN: Sometime last year I was called into consultation by a concern here making a transparent screen. They wanted to have a thoroughly satisfactory projection on such a screen and asked me to devise for them a special lens for their purpose. Obviously a transparent screen acts in an entirely different way from an ordinary screen which is illuminated in the direction from which the observer looks at it. In a transparent screen the observer looks, as you might say, directly into the projecting lamp. If the screen were entirely transparent, say, a plate of glass, an observer in the center of the room would see absolutely nothing but the center of the picture bounded by the fully illuminated opening of the lens; an observer seated at one side of the room would see nothing except a part of the extreme edge of the picture bounded by the lens opening which, however, is now no longer circular but very much foreshortened; thus an observer at the side of the hall will get very much less light than one in the center even in the direct line of vision, owing to the lens aperture being cut down by the mount. If we make the screen partially transparent the amount of light in the line of direct vision is reduced and at the same time the remainder of the screen becomes partly self-luminous, but this luminosity decreases rapidly with the angular distance from the

direct line of vision. It will thus be seen that an observer in the center of the hall may get a fairly good general picture in which, of course, the center is by far the brightest, while to an observer at the side of the auditorium the part in direct line of vision from the lamp to his eye will be the brightest but the other side of the picture will be so dark as to be practically invisible. I am of the opinion that this is a fault of all transparent screens that can not be eliminated.

DR. H. GAGE: We have in Mr. Taylor's paper with the exhibition given by Mr. Traeger of this apparatus manufactured by Leitz, what I can say is a remarkable demonstration of optic projection, particularly, opaque projection. I think it is the best example of opaque projection which I have ever had the privilege of seeing, and I wish it understood that some of the remarks which I am going to make are in no way a criticism of the manufacturers of projection apparatus. The manufacturer has to supply what the customer thinks he desires, and cannot always educate the customer to take apparatus which is best suited to the particular kind of projection which is to be used.

I wish to make a few remarks on the way projection apparatus should be made. In the first place, the apparatus here demonstrated is a combined apparatus so arranged as to allow the use of all forms of projection interchangeably on the same machine. If a person were to design a complete war vessel, he would like to combine in the same ship a dreadnought, a submarine and a flying machine, and we have something the same kind of compromise to make when we try to combine in one machine the four principal types of optic projection; the ordinary lantern slide projection, opaque projection, microscopic projection, and moving picture projection. The burden of my remarks is that the best design for opaque projection is essentially different from the best design for microscopic projection, for lantern slide projection or for the other forms.

This instrument is a good example of the design necessary for opaque projection. There is a searchlight to begin with, requiring about thirty amperes direct current to operate, which involves heavy wiring. With opaque projection, the light is diffusely reflected from the paper or other object in all directions; consequently, only a small percentage of it can get through the

objective. Something like 3 per cent. of the diffusely reflected light flux will go through a large sized objective. With opaque projection, one good way of calculating the possible illumination on the screen is to assume that the objective is completely filled with light, that is, it is considered as a light source, of the intrinsic brilliancy of the object illuminated. The illumination on the screen is proportional to the intrinsic brilliancy of the surface illuminated, multiplied by the area of the lens, and divided by the square of the distance from the screen. Hence, to secure good results with an opaque projector, bring the whole apparatus close to the screen, use a short focus objective of as large a diameter as it is possible to get, and use a searchlight to illuminate the object.

For ordinary lantern slide projection, the diagrams, (Figs. 6 and 7) given by Mr. Taylor in his paper, show about the path of the rays through the apparatus. For moving picture projection, and microscopic projection, one must take into consideration the fact that the arc light can no longer be considered as a point source, but is an extended source, and that in moving picture projection, it is necessary to illuminate an object slightly less than one inch wide and three-quarters of an inch high, the illumination over the entire surface being even, in order to prevent streaks. In microscopic projection as actually used in histology and embryology, the greatest flexibility of different microscopic powers is needed. The lecturer may wish to demonstrate during half of his lecture sections of the spinal cord, perhaps showing a diameter of fifty millimeters. There may be one or two of these sections in which he will want to go immediately from that large size down to a sixteen millimeter objective, or even an eight millimeter objective. This requires a convertible apparatus of a different sort, one which can be changed rapidly from a high power to a low power, rather than changed from microscopic projection to opaque or to lantern slide projection. The great requirement when showing microscopic specimens is ability to change rapidly from high power to low power. The cost of making this combined apparatus convertible from the ordinary lantern slide projector to the projection microscope without losing any of the flexibility required of the projection microscope is a good deal greater than to make two separate pieces of apparatus.

With all forms of projection, the direct current carbon arc is the best, but other light sources can be used, such for example as the tungsten, lime light, or acetylene. With microscopic projection, the only really satisfactory light source is the direct current carbon arc. With opaque projection, the object must receive an intense illumination, the direction from which this illumination comes being unimportant. Microscopic and moving picture projection use *directed* light, and the area and intrinsic brilliancy of the light source and the area of the objective play an important part. Where we have very small objectives, as in the microscopic case, it is impossible to get the light necessary for good projection, except with the most brilliant light source available. With moving pictures, the objectives are big enough so that it is possible to operate successfully with tungsten lamps of special type. Intrinsic brilliancy of arc and tungsten sources are given below.

TABLE I.—INTRINSIC BRILLIANCY OF SOURCES.

			Intrinsic brilliancy candlepower per sq. centimeter
Direct current arc	Solid carbons		15,800
	Cored carbons		13,000
Tungsten (Langmuir formula)		Absolute temperatures	
Highest temperature useable		3,250°	3,750
Temperature of 20-ampere, gas-filled lamps		2,850°	1,225

This table shows that with the gas-filled lamps operating at highest efficiency practicable, the intrinsic brilliancy is less than one-tenth that of the direct current carbon arc.

The intensity of screen illumination is a matter to which I have seen no references in any illuminating engineering papers. The results of some experiments made in Cornell several years ago are given below and may be taken for what they are worth, *i. e.*, first approximations.

In a dark room with clear lantern slides 2.5 foot-candles would answer, while 5 foot-candles gave entirely satisfactory results. In a room lighted from the back with incandescent lamps enough to take notes, 0.7 foot-candle on the screen from the lights, and 6 foot-candles from the lantern gave good projection, that is during a lecture to students, and there was plenty of light to spare. With the ordinary lantern slide, it is better to light the

room dimly so that the students can take notes, than to have it absolutely pitch dark. With opaque projection, it is necessary to have the room pitch dark and work with a lower screen intensity. For moving picture films about 3 foot-candles are required.

TABLE II.—INTENSITY OF SCREEN ILLUMINATION.

(1)	In a perfectly dark room an illumination of 1 foot-candle is satisfactory for transparent microscopic specimens stained red.	1 foot-candle
(2)	Dark room—lantern slides—2.5 foot-candles will do with reasonably clear slides.. ...	2.5 foot-candles
(3)	Dark room—five foot-candles entirely satisfactory..............................	5 foot-candles
(4)	Room lighted from back with incandescent lamps enough to take notes	srceen 0.7 foot-candle lantern 6 foot-candles
(5)	Room lighted from window at sides...... ..	0.85 foot-candle
	" " " entire incandescents....	1.5 foot-candles
	Fair results secured from lantern...........	5.4 foot-candles
(6)	Dark room, somewhat thick moving picture film—average illumination..............	3.0 foot-candles

TABLE III.—MINIMUM AVERAGE ILLUMINATION GIVING SATISFACTORY MOVING PICTURE PROJECTION.

		Foot-candles
1.	Tinted film	2.7 3.9
2.	Yellow tinted film............................	5.6 8.5 3.3 3.3
3.	Black and white dark film	6.0
4.	Blue colored dark film.........................	26.2
5.	Black and white dark film	25.5
6.	Hand colored film..............................	3.1
7.	Hand colored different part.....................	16 8.5
8.	Black and white dark film	30
	MAXIMUM ILLUMINATION.	
9.	Dark room and light film, too much screen illumination at..................................	75

The values for the average screen illumination are taken with the film removed and the shutter revolving.

I should like to see similar studies made of the conditions necessary for good projection, but made with greater thoroughness, in order that the illuminating engineer could be of greater service in

planning the lighting of theatres and lecture rooms, and the installation of projection apparatus.

Mr. J. L. Minick: In connection with this question of arc versus incandescent lamp for projector work there is one fact that seems to have been overlooked. This fact was brought to my attention in connection with some locomotive headlight work in Ohio with which I was connected several years ago. It was found that objects which could be seen with arc headlights of a given apparent beam candlepower could be seen with incandescent lamp headlights of considerable less apparent beam candlepowers or at much greater distances with the same apparent beam candlepower.

We had no means of determining definitely the reason for this difference. We therefore assumed it to be due largely to the difference in color value of the two beams of light and to some extent to the constant flicker and shifting of the arc. The fact that the light from the arc lamp contains a high percentage of blue may be a possible explanation of why apparently less light is required when an incandescent lamp, which is rich in red, is used.

Mr. L. C. Porter: Mr. Taylor has mentioned the increasing use of the incandescent lamp for the stereopticon. I want to say just a few words as to the primary differences between the stereopticon equipped with an arc lamp for a light source and equipped with an incandescent lamp.

The incandescent lamp has already, one might say, captured the field for home use, and small stereopticons and projectors for lecture service, due to its greater convenience, simplicity, safety and other well known factors. In all probability it will, in the very near future, take a good deal of the larger work too. In fact, for motion picture projection, we are already able with an incandescent lamp to equal the results from a 50 ampere alternating current arc, or from a 25 ampere direct current arc.

A few of the primary differences are these: In the common form of projection lantern, we have two condensing lenses (Fig. A) and light from the focal point of lens A will be made practically parallel as it goes through. If you use an ordinary lamp filament, *i. e.*, a filament as shown in Fig. B, a light ray L_2,

coming from a point P, away from the focal point would be scattered when it went through the lenses, and similarly from all other points outside the focus. For that reason the ordinary lamp filament cannot be used for projection. To get satisfactory projection, it is necessary to concentrate the filament as closely as possible around the focal point of the condenser.

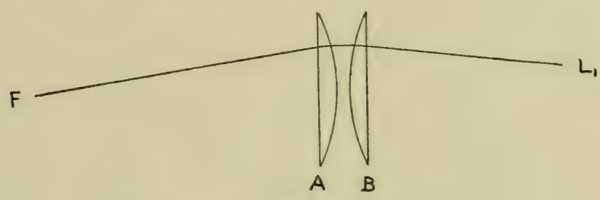


Fig. A.

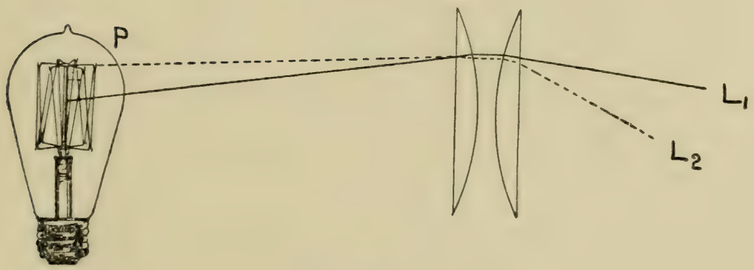


Fig. B.

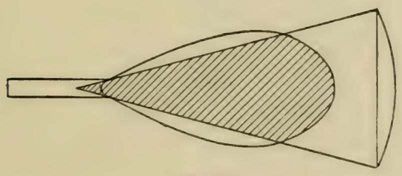


Fig. C.

In arc lamps, the light comes from the crater of the carbon. The distribution of light from such a crater is somewhat as shown in Fig. C; therefore, a condensing lens of tolerably long focal length will utilize a very large percentage of the total light, as shown by the shaded portion of Fig. C. On the other hand, if you put an incandescent lamp (which has, practically speaking, a spherical distribution, *i. e.*, the candlepower is equal practically in every direction with the exception of under the base) at the same

point as the arc, using the same condenser, you utilize a very small percentage of the total light flux, as shown by the shaded portion in Fig. D. Therefore, when one uses an incandescent light it is necessary to use a short focus condenser so that you utilize a larger percentage of the total light flux; and that can still further be increased by putting a spherical mirror back of it, as illustrated in Fig. E. With an arc light source the screen is practically an image of the crater of the arc and that gives you a uniform field. With an incandescent, if the light source is exactly at the focal point, you get an enlarged image of the filament on the screen, which is more or less objectionable. To get rid of that it is necessary to move the light source a little out of focus, or use other means of breaking up the filament image.

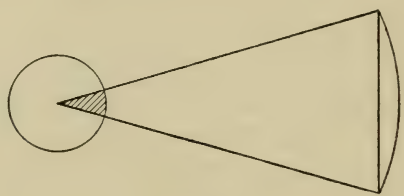


Fig. D.

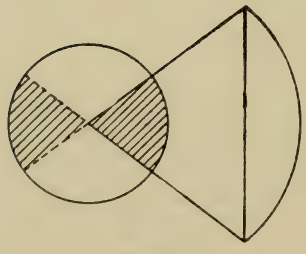


Fig. E.

In regard to Dr. Gage's figures, twenty-five foot candles for moonlight work seems to me a little high. When one comes to night scenes, one wants to think of darkness. We found that we could get very good moonlight scenes with from six to ten foot-candles. According to Dr. Gage, I should estimate that about three to six foot-candles is considered good illumination on the screen in average moving picture work and we are at present able to obtain that from an incandescent light source.

Mr. M. Luckiesh: I believe this Society should become more interested in vision as influenced by moving pictures. No doubt all of us while viewing motion pictures have experienced considerable visual discomfort from two chief sources of eye-strain, namely the brightness contrast of the highly illuminated screen amid relatively dark surroundings and the more or less evident flicker. The discomfort due to both of these causes can be lessened by illuminating the entire room slightly. In many cases I believe the illumination intensity on the screen is too great. However, if excessive intensity of illumination is available, I would suggest that considerable general illumination be provided. Where this is done the results are very satisfactory. Even in some cases the slight amount of light provided by the orchestra lamps makes the brightness contrast between the screen and its surroundings quite endurable compared with the condition when the orchestra lamps are unlighted. Sometimes, however, these lamps are very glaring.

Another point of interest which has received little attention is the relation of the illumination intensity on the screen to the conspicuousness of the flicker. It is well known that the critical flicker-frequency, or the frequency at which flicker disappears, increases slowly with the increase in the brightness of the surface which is being alternated against darkness. The flicker frequency has been shown to increase approximately proportional to the logarithm of the brightness. There is reason to believe that there is an optimum relation between illumination and the noticeability of flicker in moving picture projection which is not the condition found in some movie theatres. Another point of interest is found in the contour of the flicker or the wave-form of the brightness. I have shown (*Physical Rev.*, 1914, Vol. IV, N. S. July, p. 1; *Elec. World,* May 16, 1914) that the critical frequency decreases as the change from light to dark becomes less abrupt. This and other points are of considerable interest in the design of moving picture projection apparatus. In fact the "movies" present a comparatively unexplored field for those interested in the aims of this Society.

MODERN ASPECTS OF FACTORY LIGHTING AND THE NEW CODE.*

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Synopsis: An analysis of causes which have led to greater attention on the part of factory owners and employers to the conditions under which their employees work; with reasons why, at the present time, there is a demand for accurate information on how properly to light factory spaces. Reference is made to the new "Code of Lighting for Factories, Mills and Other Work Places," recently issued by the Illuminating Engineering Society; the reasons for its preparation are given; its probable field of usefulness discussed; and points in this Code which are most likely to advance the status of factory lighting and to raise the standards of quantity and quality of light for industrial purposes, are explained.

The president of one of the largest manufacturing concerns in this country, when referring to general phases of the work in his plant on one occasion, used the expression: "This is a big problem which we are all trying gradually to solve."†

The thought involved in these words is one which many are apt to overlook in connection with industrial work. The processes of manufacture, the relations of employer and employee, the environment under which the work is done, may all seem to the layman as items which are clearly defined and he may often wonder why the day's routine should be marred at times by misunderstandings and hindrances of larger or smaller proportions. If the layman could be given an insight into the vast number of factors which go to make up this *problem*, not only would he see it more clearly in its true light as inherently complex, but it would present to his mind many unusual difficulties.

CONDITIONS SURROUNDING FACTORY WORK.

One of the difficult elements of this problem is unquestionably that of the conditions under which work is performed. This

* A paper presented at a joint meeting of the New York Sections of the American Society of Mechanical Engineers and the Illuminating Engineering Society, Mar. 14, 1916.

The Illuminating Engineering Society is not responsible for the statements or opinions advanced by contributors.

† In an informal address by Mr. E. M. Herr, President, Westinghouse Electric and Manufacturing Company, to foremen and other employees of the plant.

element has a number of component parts, some of which directly influence the health, comfort and efficiency of the employee, and an analysis of the forces at work on the improvement of factory conditions should direct attention at the outset to the item of inertia, which is often manifested by a tendency to view with satisfaction things as they happen to exist at any given time. The expression on the part of factory owners is sometimes heard that their work has been conducted heretofore under existing conditions, why not leave well enough alone.

The actual working conditions in many factories are such that it is necessary even in these days to emphasize the obvious principle that life, whether in the home, the office or the workshop, demands for its welfare a fairly definite kind of environment, if its forces are to be conserved. The idea, therefore, that one set of living conditions is a standard for the home or office, while another constitutes that of the factory, may well be looked upon as a handicap in this respect to the factory workman, which makes his effort to maintain health a more difficult task, than that of the more fortunate who labor under better surroundings.

IMPORTANT FACTORS IN ENVIRONMENT.

It is hardly necessary to enumerate the factors which go to make up these conditions, but a simple illustration will bring out the point. Take the office, for example. It is important here to maintain suitable temperature during winter and summer months; to supply pure fresh air, adequate light by day from windows sufficient in size to admit a generous supply of natural light and by night from artificial illuminants properly placed and in such numbers to meet ordinary needs; to maintain cleanliness and sanitary conditions; to have available pure water for drinking purposes; and to provide proper ventilation for the removal of impure air. This is a list of primary requirements. They may seem trivial when compared to items of larger interest, but they make life tolerable or intolerable by their presence or absence.

Even to the casual observer of industrial life, and this reference applies mainly to those cases where modern ideas of factory construction and sanitation have not yet made an appeal, it is a most striking thing that a difference is set between the standards of environment in the shop and elsewhere. This is incon-

sistent, because the common factor—*human life*—enters into each case. On this basis alone, there should be no difficulty in accepting the proposition which forms the underlying thought of this paper, namely, that the fundamental requirements for comfort, health and efficiency, are applicable, not in a restricted sense to the home or to the office, but that they should be looked upon as inclusive, and as applicable, in a general way at least, to industrial conditions.

INDUSTRIAL CHANGES.

To accept this principle, it follows that the temperature in which the worker finds himself day by day, although not a condition over which he ordinarily has any direct control, should be maintained at a suitable value for health's sake as well as for the sake of the improved workmanship which invariable accompanies it; similarly, adequate ventilation, avoidance of the danger of gas poisoning, and the proper installation and maintenance of lighting facilities are important.

That the employee has greater difficulty in these days to voice his protest against intolerable environment may be illustrated by going back to the earlier days when the proprietor of a small factory gave personal supervision to a handful of employees, whose interests were his interests and where the complaints of the few were easily met because conditions were so simple in contrast to much of the factory life of the present day. Now thousands of workmen take the place of the smaller numbers, and in the larger plants, a small group of employees reports to a sub-foreman, he, in turn, to a foreman, then, next in line, to the general foreman, the assistant superintendent, superintendent, general superintendent, and perhaps a manager of works, all representative of a complex organization. It is not quite natural, therefore, that the employer has tended to become more or less impersonal? Complaints of the individual must necessarily traverse a labyrinth of large proportions before reaching the almost invisible force which guides the destiny of the working classes. If this guiding force fails in the appreciation of the needs of the case, there is little assurance that changes, so long necessary, will be effected.

INDUSTRIAL GROWTH.

Statistics[1] show that in fifty years between 1850 and 1900, the gross population of this country increased by about 200 per cent., but the wage earners in manufacturing increased by about 400 per cent. in this same fifty year period. In 1850 4 per cent. of

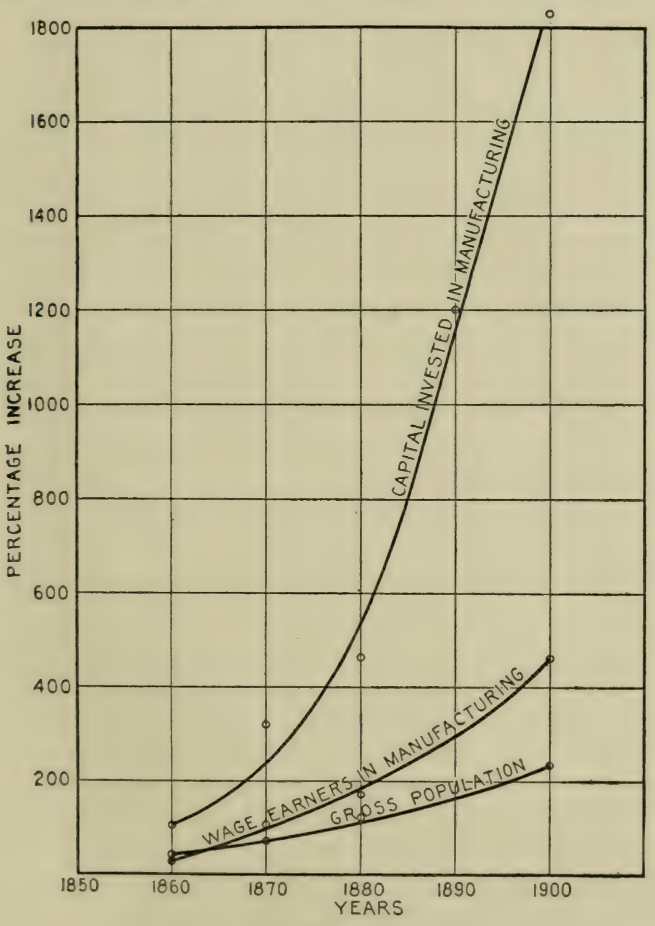


Fig. 1.

the total population were wage earners in manufacturing, while fifty years later the number had increased to 7 per cent. of a greatly increased total population, and in some individual states to over 20 per cent.

[1] From information compiled in the United States Census Reports.

In fifty years the capital invested in manufacturing has increased by over 1,800 per cent., the iron and steel industry in thirty years over 400 per cent.; and the use of electricity has increased nearly 100 per cent. in the extremely short period of five years. Fig. 1 shows in a very striking manner how much more rapidly the percentage increases of invested capital and wage earners in manufacturing have taken place than the corresponding increases of total population calculated on the same basis.

Is it not reasonable to conclude that this phenomenal growth has resulted in an unusual effort to keep up with the demand for greater output, often to the exclusion of interest in the physical surroundings which so directly affect the worker? New factory space has repeatedly been required on every hand. Many plants from necessity have rapidly developed and expanded in size, and new buildings, often of a temporary nature, have been added, sometimes at great distances from the central heating and lighting systems, only later to become a permanent part of the entire plant. Those responsible for the manufactured product have thus perhaps naturally been led to overlook many items of comfort, convenience and efficiency, which at the time may have seemed to possess no direct relation to the output.

NEW INFLUENCES.

Stabilizing influences have gradually begun to develop. Departments for considering the welfare of the employees have been formed; safety first organizations have come into existence; organized labor has, in a way at least, moulded public opinion in its favor where the employer has grossly neglected its rightful interests; the efficiency movement has directed attention to those causes which result in avoidable time losses. Among these causes have been included poor ventilation, inadequate lighting, and the gloomy shop conditions which, in the past, have been so common.

Through the efficiency movement attention has been given to such cases which are typified by a workman who stands before his machine, but who must hold his finger on the rule when measuring the piece of work, and then walk across to the nearest window to see the markings of the scale, simply because his machine is not properly lighted. This homely illustration has been one of the many examples of time losses affecting production costs.

PHYSICAL AS WELL AS ECONOMIC LOSSES.

There is, however, another side. Unnecessary motion reduces the physical resources of the workman. The poor light affects his vision, produces eye fatigue prematurely and increases the risk of permanently impaired vision. It follows, however, that while the employer is first concerned with the economic aspects, the installation of suitable means for reducing these financial losses also aids the other feature of health and comfort of the man at his machine. No matter, therefore, which manner of approach is assumed, either the economic, or the desire for improved physical working conditions, the whole matter is helped.

Another possible influence is hinted at by Dr. G. E. de Schweinitz, the eminent opthalmologist, who in discussing the question of conservation of vision in a recent address,[2] raised the following point: "Would it not be a good thing if there was a department of the National Committee for the Prevention of Blindness to which application could be made for the latest information on illumination?" The thought involved here is that from the purely medical standpoint, it is beginning to be recognized that the element of illumination should be made the object of scientific study for determining the best ways and means to conserve eyesight, and furthermore to make this information available to the industries and others interested.

The whole situation is summarized very well in the introduction to recent legislative orders in the state of Wisconsin, where the following statement is found: "There is a general awakening over the country among manufacturers to the economic value of conserving the human equipment in their plants, and there never was a time when so much attention was being given by progressive manufacturers to the subjects of shop lighting, elimination of dusts and gases, fresh air, and general cleanliness. The manufacturers who have done the most along these lines are the most enthusiastic in the recommendation of their practical value."

ACCURATE INFORMATION ESSENTIAL.

Education up to this viewpoint, as outlined by the Industrial Commission of Wisconsin, seems to be one of the greatest needs

[2] Journal of the American Medical Association, Vol. 66, No. 6, p. 393.

at the present time, for while the foregoing paragraph hints that this viewpoint is common, there are still many locations where it is not recognized. The prevailing ignorance of the simpler items of shop environment is almost beyond comprehension even to-day in many instances, and this ignorance is not usually due to inability to master the points involved, but rather *because such matters have never heretofore been given attention.* This latter kind of ignorance responds, as a rule, to carefully directed educational efforts, which try to show to the employer not only the ways and means to follow, but makes him face squarely the financial and other losses which result from neglect.

PRELIMINARY WORK OF CODE COMMITTEES.

As a preliminary to the work on the new code, a study was made of some of the existing lighting legislation. The shop lighting orders of Wisconsin and the legal enactments of New York state, have stood out most prominently in this study, the efforts in these two states being representative of the most systematic work along this line up to date. Complete digests of all legislation related in any way to lighting were also obtained at considerable expense from one or two other states, and less complete data from a number of others, and these indicated conclusively that nothing of any practical value exists in a majority if not all of the state laws concerning the regulation of industrial lighting.

In 1914 the Industrial Commission of the state of Wisconsin issued a handbook on shop lighting for superintendents and electricians in connection with its orders on shop lighting, and the general scheme of this handbook, which serves as a supplement to the legislative requirements, has been followed in the development of the new code.

IMPORTANCE OF PROPER VIEWPOINT.

In presenting this code, the committees have accepted and emphasized a number of means whereby lighting improvements may be encouraged in the industries. These include influences, some of which are not based on legislation, and which have been looked upon as a good and sufficient reason for drafting the code in more or less popular language rather than in legal phraseology. This plan is considered of special advantage because it permits any factory owner or manager to take the intent of the various

articles and apply them to his own individual needs, and at the same time the subject matter is so arranged that a legislative body may readily transform it into regulations suited perhaps to particular local or special requirements, either independently or through the co-operation of the Committee on Lighting Legislation.

Among the influences which the committees have recognized as having been effective in the past, and which may be looked to in the immediate future to aid in raising the standards of factory lighting, the following are of special importance:

(*a*) The interest of factory owners and executives in the economic returns promoted by better lighting.

(*b*) The effect of public opinion, indicated by the popular and technical press, in directing attention to better factory environment.

(*c*) Compensation laws and their effect in bringing about improvements in methods for preventing accidents.

(*d*) State and municipal legislation which tends to place industrial lighting on at least a minimum standard basis.

REQUIREMENTS OF THE NEW CODE MODERATE.

The fact that many industrial plants in states not having lighting legislation, possess illumination facilities of a higher standard than are required by the legal enactments in those states which have adopted such laws, or than are required in the regulations of the new code, is an indication that much dependence can safely be placed on influences other than legal requirements in the efforts to improve the lighting in the industrial field. At the same time, ignorance of the possibilities and neglect are apt to prevail in many instances, and it is for these cases that legislation is particularly needed.

This point is emphasized in the recent British Report of the Departmental Committee on Lighting in Factories and Workshops, where the following statement[3] is found:

> On the other hand, it must be admitted that many employers have lagged behind in the general advance. This applies especially to old factories, designed before the importance of illumination was generally recognized, and to small workshops, of which the occupiers perhaps hesitate to expend the capital necessary for improvement.

[3] First report of the Departmental Committee on Lighting in Factories and Workshops, Great Britain, 1915, p. 13.

It is obvious that any requirement which would tend to bring such places up to the level of the more progressive firms would be beneficial, not only to the operative by improving his working conditions, but also to the employer himself by increasing his output. Light is a cheap commodity, and little or no hardship should result from such requirement, if gradually and sympathetically enforced.

To those who have given some study to the questions of factory lighting, it will be apparent that the field is very complex, and this feature has introduced difficulties in the preparation of the code. After a review of the points involved, it was decided that the most logical method of procedure was to draft out the articles in such a way as to cover a number of representative cases so distributed to include the probable extremes. To offset the inability to place any given factory section in its proper class, when none of the listings in the code seem to fit the circumstances, it has been suggested in the treatment that expert assistance be relied upon.

The code consists of three main divisions, the one at the outset contains eleven articles suggested as a basis for legislation; a second includes eight important rules which should be observed in factory lighting practise, and which are intended somewhat in the nature of a supplement to the articles themselves; and a third division is devoted to explanatory notes of considerable length bearing on the fundamentals of modern illuminating engineering with special reference to factory conditions.

BRIEF ANALYSIS OF THE CODE.

A brief analysis of the code articles shows that they cover both natural and artificial lighting and that artificial lighting is treated from the standpoints both of gas and electric supply. The important features of natural lighting, which are discussed at considerable length in the explanatory notes, have therefore been looked upon as equally, if not more important, than those pertaining to artificial light, although it has been possible to treat the latter somewhat more in detail. In a general way, however, such topics as maintenance, for example, have been so worded as to apply either to natural or to artificial lighting.

The method of specifying the quantity of illumination on a basis of intensity is in accord with modern practise. In one instance of state legislation reviewed by the committees, quan-

tity has been specified in terms of candlepower per square foot. *This is open to the great objection that it does not specify the illumination on the work as a very important feature.* The intensity values given in Article V of the code, seem to meet this objection successfully, while the appended paragraphs give the candlepower per square foot equivalent for a given intensity value, thus rendering the method intelligible to the average mind. It is most important to note, however, the recommendation that a portable photometer or illuminometer be employed for the determination of intensities in existing systems and particularly where uncertainty prevails.

Importance is also attached in the code to the proper lighting of roadways, yards, stairways, passages and places not usually frequented from the standpoint of safety. Records of industrial accidents indicate the need of greater care in providing light for the more or less out of the way places.

AUXILIARY LIGHTING.

In Article XI, reference is made to auxiliary lighting. This is a safety-first precaution and follows from a similar ruling in many of the buildings coming under the control of the Bureau of Water Supply, Gas and Electricity in New York City, particularly such buildings as are occupied by large numbers of people. Throughout the code, accident prevention and its relation to better lighting is made the basis of frequent comment.

As an encouragement to improvements in factory lighting, the more important advantages of good lighting have been compiled into a list of the kinds of things which have been proved by the experiences in this field during the past few years. These are:

1. Reduction of accidents.
2. Greater accuracy in workmanship.
3. Increased production for the same labor cost.
4. Less eye strain.
5. Promotion of better working conditions.
6. Greater contentment of the workmen.
7. More order and neatness in the plant.
8. Supervision of the employees made easier.

It will be noted that items 4, 5, 6, 7 and 8, in addition to item 1, all have a bearing on accident prevention.

INTERIOR FINISH.

Emphasis is placed in one of the sections of the Explanatory Notes on the wisdom of light interior finish, both in reinforcing the direct illumination and in giving better diffusion, which in turn adds to the amount of light received on the sides of a given piece of work; and a complete section is devoted to the question of side light, that is, light on working surfaces other than the horizontal, both as to its important bearing on successful factory lighting, and also ways and means for improving these components of the illumination.

One of the sections of greatest value in the *Explanatory Notes* is that dealing with *Maintenance*. It is believed that while the importance of this feature may not appeal to every user of light, a consideration of the points which are set forth in this section will interest every factory manager.

It has been felt that the scope of the code should include a reference to some other features of eye protection, in addition to those related to proper lighting, and it has therefore been urged that those responsible for the health and welfare of employees, devote the necessary attention to eye protection against injury from such operations as electric welding. In this particular instance reference is made to the protective glasses for the eyes of the operator, and to the fact that these glasses should not be judged as to their protective properties by visual inspection, but rather on a basis of an analysis of their spectral transmission of invisible radiation. Other items of this same general character are mentioned.

USE OF PHOTOGRAPHIC ILLUSTRATIONS.

As a general policy in the code, photographs have been employed to illustrate the varied features of good and bad lighting. In the use of such views the captions have been so worded that the reader may easily detect the main points which the illustration is intended to show. The use of photographs for this purpose must, of course, be based on a careful selection of views which actually do indicate some important phase of the illumination problem.

Figs. 2 and 3 would come under the head of useful photographs from the illumination standpoint, because they show by contrast

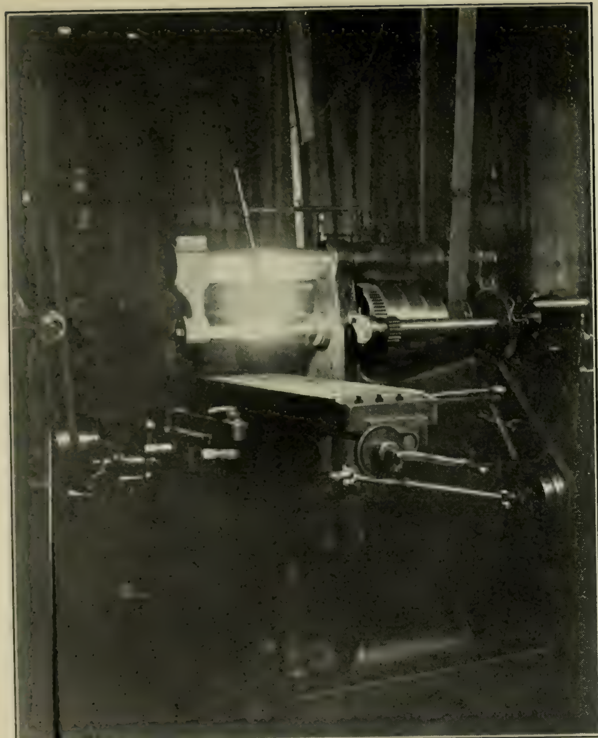


Fig. 2.—Machine tool with its own lamp. The lamp, however, has no reflector and the glare to which the eyes of the operator are subjected is shown to some extent in such an illustration.

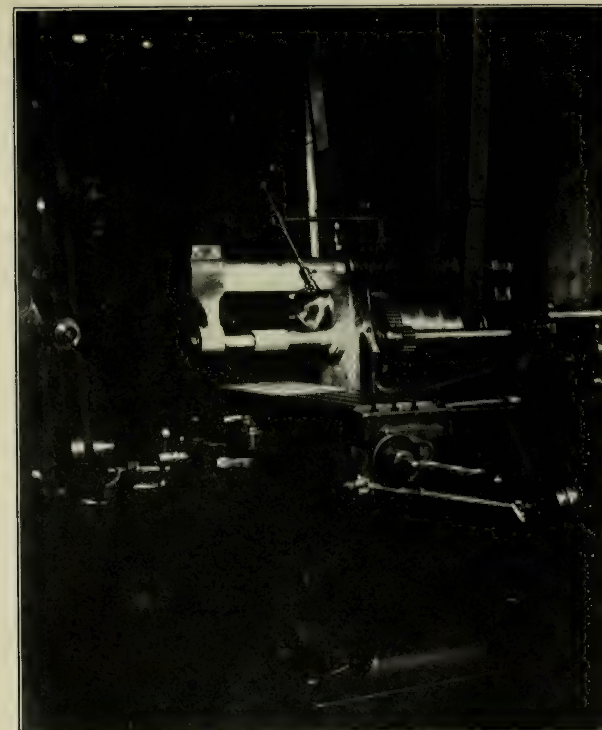


Fig. 3.—A view of the machine shown in Fig. 2, but the lamp is here provided with a metal reflector. The comparison of such an illustration with one like Fig. 2 gives an idea of the contrast between an unprotected and a protected lamp.

Fig. 4.—This is representative of a poorly arranged lighting system. A comparison of such an illustration with one like Fig. 5 gives an impression regarding the advantages of properly arranged lighting units.

Fig. 5.—A well designed lighting system. Many points are brought out by such a view illustrating the advantages of well planned systems, particularly when a comparison can be made with a view like Fig. 4 where the same class of work is conducted.

Fig. 6.—A view like this shows positively nothing in connection with the illumination results to be obtained by the lamps. This is a day view of a foundry; the picture shows merely the locations of the lamps.

Fig. 7.—This night view contrasted with Fig. 6 indicates many of the points of excellence which can be obtained from the illumination standpoint with lamps of the same type as shown in Fig. 6.

the evil effects of a bare incandescent lamp located almost directly in the line of vision. Figs. 4 and 5 also might be classed as useful in that they show by contrast a very poorly arranged system and a well designed lay-out. Fig. 6, however, shows nothing in relation to artificial illumination because the view is taken by day merely with the lamps turned on. Fig. 7 is a view of a system of the same kind of lamps as those used in Fig. 6, but is taken at night and consequently indicates many interesting points in the distribution of the illumination and in the arrangement of the lamps. These cases are explained only because they illustrate that care is necessary in making a selection of suitable photographs for such a publication, and the code will be found to contain about the best set of lighting views which are available at the present time.

NOTES ON THE ENFORCEMENT OF THE CODE.

The question of ways and means for enforcing such a code has come up for considerable discussion. Many difficulties present themselves at first thought because of the extreme variations in illumination intensity from natural light sources, such as windows, skylights, and the like, and because the conditions in the average factory include such widely variable characteristics. Conferences with the Commissioners of Labor in two states have indicated that the enforcement of the requirements of such a code, while unquestionably difficult, can probably be handled in such manner that many, if not all, of these difficulties can be overcome. Much depends on the viewpoint taken by state departments, and if this is such as to encourage a study of the reasons back of the requirements as well as the methods of accommodating conditions merely to meet them, there is every reason to believe that radical and far reaching improvements will replace much of the industrial lighting which to-day must be classed as far below even the minimum requirements called for by the new Code.

DISCUSSION.

MR. JOHN E. BULLARD: The glare of a lamp is a problem that has been brought out once or twice. Prof. Clewell brought out the point that we judge lighting intensities by looking at the light sources. One point, however, that I have never heard mentioned very much and which I have often encountered in the past ten years, while endeavoring to introduce better lighting in factories, is that many workers apparently become addicted to the habit of glare to the same extent that other workers become addicted to the use of whiskey. Too much whiskey is bad for the worker as is too much glare. I have found in this past winter, right here in New York City, that if one goes into a shop, especially in the cloak and suit business, where sewing machines are used, and hangs up units with diffusing glassware which practically reduces the glare to nothing, making the light source perfectly safe, the workers will insist that they have not enough light. When the diffusing glassware is removed and the glare is present, the lighting is perfectly satisfactory. The lighting, of course, is not so good after the glassware has been removed, as it was before, but it satisfies the workers. In other factories that have been more or less properly lighted right along, the glare can be reduced and perfect illumination obtained and everybody will be satisfied. It seems to be quite a problem to overcome that habit employees have of looking at a glaring lamp. The candlepower may be increased by say one candlepower over the working plane, but if they cannot look at a light source with glare to it, so that it nearly puts their eyes out, the workers insist that there is not enough light. It seems that the workers become accustomed to being blinded and unless they are blinded they think they cannot see anything. They have apparently trained their eyes to look at a light source that makes it impossible for them to see the work satisfactorily afterwards. This has been a very serious problem in my work. It is a very difficult one to overcome. I suppose it comes more under the head of psychology than illuminating engineering.

In a talk given before the mid-winter convention here in New York, Prof. Munsterberg showed that illuminating engineering and psychology run very closely together. Often in the illum-

inating engineering laboratory one works out a lighting system that is perfectly satisfactory, but when it is installed in a factory all the workers threaten to strike. It seems to be a good deal like a football player that I knew who played on the college team through the season. The manager had promised the players that if they beat the University of Chicago, they were to have a banquet. They all played hard and did beat the University of Chicago. Accordingly they went to the best hotel and had a banquet. Of course they had champagne. It happened that this fellow was not in the habit of drinking champagne, and when they passed him his glass, he said, "I do not want that *cider* give me some beer." It is the same way with these workers. They don't want diffused light, they want glare.

MR. H. S. WYNKOOP: I am not qualified to discuss Prof. Clewell's paper from the standpoint of illuminating engineering; but I know something about codes, having been engaged for the past eighteen years in enforcing an electrical code in the City of New York, and being at present the city's representative on the United States Bureau of Standards' Committee on the Safety to Life Electrical Code. It seems highly appropriate that a national organization should establish a code relating to matters which come within its scope. There is a very general effort in every line of nation-wide industry to come to agreement upon a set of fundamental principles which may serve as the basis for legislation or adjudication, or, at the least, as a guide to good practise in specification writing or in actual construction. But a national code should be suggestive, not mandatory. It should confine itself principally to stating the results desired and the minimum of compliance therewith. It should not be so verbose as to read like a primer, nor so brief as to be indefinite and thus lead to wrangles over interpretation. My own impression, after a careful reading of the proposed lighting code, is that it is somewhat too brief to serve as the basis of clear-cut legislation or as a manual to be placed in the hands of an inspector. The ways and means for enforcing a lighting code must be left to the city or state authorities. Such legislation as may result from a code recommended by the Illuminating Engineering Society will provide the necessary ways and means.

Mr. G. H. Stickney: It has been becoming more and more evident that government regulation of factory lighting is coming. This is not surprising when one observes the very poor illumination of many factories, especially the smaller ones, contrasted with so much better lighting found in some of the larger establishments, where the advantages have been weighed. Wise laws, which actually insure good working conditions and which do not inflict absurd or unnecessary hardships on manufacturers, should be of benefit to all concerned.

The actual specification of good lighting is so difficult and so little understood, especially among law makers, that there is a danger of unwise legislation. The railway headlight laws of some states are examples of this. They require headlights that for some conditions are really dangerous, and specify them so indefinitely that the intent is not always clear, while unnecessary expense and uncertainty are forced on the railroads.

The code is an attempt to furnish a preliminary basis for correct regulation. It is hoped that it will also serve to unify the requirements in different states and other jurisdictions. As mentioned by Mr. Clewell, this code is the first of a series which the Illuminating Engineering Society plans to prepare on the principal classes of lighting. Although it has been carefully studied from various points of view, as a first attempt it will require further study and attention to adapt it to practical applications. And even when such regulations are adopted, they may be expected to grow and change with experience, the same as do the electrical and other codes. Of course, it is desirable to make it as good a code as practicable before putting it into operation, and suggestions and criticisms to that end will be helpful.

Good lighting in a factory not only benefits the workman, but actually is an economy to the manufacturer. Any additional cost of good lighting over necessary cost of poor lighting is likely to be returned one hundred fold in increased production and improved quality of finished product. This should mean that with the education of manufacturers the enforcement of a reasonable code should be very easy.

I was agreeably surprised, in discussing the question with Col. Bryant and Dr. Jackson, to learn that in their experience, over 90 per cent. of the manufacturers really try to comply with the

regulations if they understand them, the real problem being to make instructions clear and put them in common language. And after considerable study, it is evident to me that this is no simple problem.

PROF. C. E. CLEWELL (In reply): The code cannot be considered a detailed treatment of illumination from a scientific standpoint—one of the difficult objects has been to make many of these items plain.

As to the habit of glare, I think one cannot take too much care in sizing up the individual psychological qualities or characteristics of the person who is involved in seeing. It may often be the case, even when a lighting system seems perfectly correct, that there is a complaint on the part of an operative because of some basic underlying feature which is lacking to make it satisfactory. It is often advisable to study carefully the individual case, and not to jump at the conclusions that people actually want glare. There may be some fundamental item that has been overlooked.

It has not been intended to give the idea that arc lamps are obsolete. Several distinct cases of arc lighting are pictured in the code, hence the code does not give the idea that the arc lamp is obsolete, as hinted by one speaker. As to the use of frosted type C lamps 10 feet above the floor, with flat reflectors, it would seem, at first thought, that this would probably be a very objectionable system of lighting, although it may not be as bad as it sounds.

It has been urged that the code ought not to be mandatory, but rather suggestive. It is so intended. Although it states that certain conditions must be fulfilled, those who drafted the articles had legislation in mind, but the intent is suggestive; in fact, that is the province of the document in its present form. One criticism has been that the code is too brief, another that it is too long, so that I think the spirit back of its preparation will have to stand as the explanation of its present length.

As to window areas, in the explanatory section of the code there is a section on calculations of intensity from given window areas. I am going to suggest that the speaker, who asked the question on the window area, refer to a copy of the complete code. There was no attempt to specify the angles at which the light entered to a satisfactory extent in certain departments.

Actual cases from practise were taken as a basis for the illustrations.

It would seem that the question of coloring lamps in order to get rid of glare is going at the thing in a more or less backward way. Why not get the lamps up high enough so that they are out of the line of vision? If they are down close to the work, the thing to do is, in general, to raise them, rather than to surround them with coloring to reduce the glare.

The three times minimum intensity requirement for daylight was arrived at on a basis of judgment. Cases of natural lighting were known, and three times was included more or less as an arbitrary value. The British report does not make any distinction between natural and artificial light.

In answer to the question whether monochromatic light had been looked into, the committee does not attempt to make any distinction in this code for different colors, nor does the British report make any such distinction. I asked this same general question of Dr. Steinmetz a few weeks ago, and his answer seemed to indicate that the question is rather too involved to warrant its being included in such a code. There is, of course, a good deal to that particular phase of the problem.

As to surroundings as a factor in reflection, one speaker has stated that twenty-five hundredths of a foot-candle might be sufficient in the case of a white stairway; while with a black stairway much more might be needed. This involves a detail in illumination design, which we can hardly hope to include in a code of this kind. Such a code must be reduced to a workable basis in the expectation that manufacturers will see fit to employ competent, expert assistance to take care of refined points of this kind.

THE INTEGRATING PHOTOMETRIC SPHERE, ITS CONSTRUCTION AND USE.*

BY E. B. ROSA AND A. H. TAYLOR.

Contents: Types of integrators: mirror integrators; the Ulbricht sphere, and its theory; types of spheres; other closed integrators. Bureau of Standards sphere: description; sphere paint; photometric equipment; cost of sphere; advantages and disadvantages. Tests of Bureau sphere: accuracy of integration; effect of foreign objects in sphere; absorption of reflected light by sphere screens; absorption of reflected light by incandescent lamps; effect of lamp position; integration of asymmetrical light source; absorption of light by sphere walls. Methods of making integration measurements. Sources of error. Hemispherical candlepower measurements. Bibliography.

Synopsis: The paper discusses the types of integrators which have been and are being used for the measurement of mean spherical candlepower, and the materials used in their construction. A detailed description of an 88-in. (2.23 m.) re-enforced concrete sphere built at the Bureau of Standards is given, with the results of various tests carried out with it. The authors point out some of the possible sources of error in the use of spheres, and give results of tests by themselves and others showing the amount and significance of such errors. A bibliography of the subject is given in the appendix.

TYPES OF INTEGRATORS.

Measurements of the mean spherical candlepower of lamps by several different types of integrators have been made at various times and places for about thirty years. The first measurements were made by the use of the point by point method, which consists in the measurement of the candlepower of the lamp at various angles in a vertical plane. These values when multiplied by the proper factors, and added, give the total luminous flux from the lamp. This method is in very general use to-day, though usually its principal object is to measure the distribution of light about the lamp. All spherical candlepower standards are originally derived from such measurements. To give reliable results the lamp tested must either be rotated about its vertical axis

* A paper read at the mid-winter convention of the Illuminating Engineering Society, New York, February 10, 11, 1916.

(since the light may not be symmetrical), or measurements must be made in several vertical planes. The results obtained by experienced observers may be quite accurate, but the work is laborious.

Other photometers for this purpose, designed to give the mean spherical candlepower of a lamp in one measurement, came into use after 1900. They were usually composed of mirrors arranged in a circular arc about the test source, so located that they reflected to the photometer screen the light given out by the test source at definite angles in the vertical plane, *e. g.*, every 10°. Some had the mirrors placed at the centers of zones of equal area, so that the candlepowers at various angles would be properly weighted. The Matthews photometer was of the former type, and the Russell-Leonard of the latter. Photometers of these types, while quite useful for some work, are open to certain objections. First of all, the mirrors have to be very carefully adjusted, and since the mirror surface cannot be depended upon to remain unchanged, they must be adjusted occasionally. The light source must be rotated if accurate results are desired. Only lamps of moderate size can be tested, unless very large mirrors are used.

In 1900 Ulbricht proposed the use of a hollow sphere, with white interior surface, for light integration. It operates on the principle first brought out by Sumpner[1] in 1892, but the instrument was developed by Ulbricht without knowledge of Sumpner's theory. Briefly stated, the theory is that the illumination on any part of the interior surface of the sphere, when a lighted lamp is introduced into the sphere, is made up of two parts: (*a*) the direct light from the lamp and (*b*) light diffusely reflected from all parts of the sphere wall. The part (*a*) varies from point to point and depends on the position of the light source and its light distribution. The part (*b*) is independent of these conditions, is the same for all parts of the spherical surface, and is proportional to the total flux of light from the lamp. Hence, it is only necessary to measure (*b*), which can be done by putting a small translucent milk glass plate in a hole in the sphere wall, flush with the inner surface, observing it by means of a photometer outside the sphere, and screening off (*a*) by means of an opaque screen between the plate and the light source. The use

of a screen, however, is a necessary departure from the conditions assumed in the simple theory of the sphere, which deals only with an empty sphere. An excellent treatment of the subject when the screen is taken into account was given in the paper before this society in 1914 by Chaney and Clark[25] and does not need repetition at this time.

Theory and practise show that the errors due to the screen can be made negligible by making the surface of the sphere very large relative to the screen area, using screens as small as possible, and having them properly placed.

Intergrating spheres have been constructed of various materials and sizes. Ulbricht's[2] original sphere was 50 cm. in diameter, made of milk glass, and had an opaque covering, the inner surface being coated with chalk. The smaller sizes of spheres in use to-day are usually made of sheet metal shaped on molds by pressure or hammering. Dr. Bloch[11] describes a sphere made of zinc plate 2 mm. thick, the two halves of the globe being built up by pressure on a model, and subsequently connected by suitable screws and wing nuts. The sizes larger than 1 meter diameter are usually made of sheet metal segments fastened to structural steel or flat steel ribs. Such spheres have been described by Dr. Monasch[6] and various other writers. Marchant[23] has described a sphere, at the University of Liverpool, 5 ft. 3 in. (1.6 m.) internal diameter, built of asbestos millboard ¼ in. (6.35 mm.) thick fastened to 46 ⅝ in. T-iron ribs, bent into circular arcs. It is made in halves, one of which is on rollers. M. Corsepius[5] has described a sphere made of hair plaster, applied to a wire skeleton framework, covered with gauze. Upon this plaster is another coat of plaster of Paris.

Dr. Monasch[6] advocates the use of a large hemisphere with flat cover instead of a sphere for certain spherical candlepower measurements, on account of its lower cost and greater ease of manipulation. He described tests of a hemisphere of 2 meters diameter which indicated that the illumination of the photometer window was practically independent of the lamp position, the differences found being of the order of 2 per cent.

Dr. Sumpner[20] has suggested the use of a rectangular box instead of a sphere, on account of its simpler construction and

lower cost. He states that there is no simple accurate formula for the relation between the illumination of a portion of the surface and the average direct illumination, but that the illumination tends to become equal at all points of the surface.

In the discussion of Dr. Sumpner's paper Prof. Ulbricht, Dr. Bloch and Mr. Dow criticize his conclusions, and state that very serious errors may occur with a cubical box. In commenting on the same paper Prof. G. W. O. Howe describes a box, 3 ft. (0.91 m.) on edge, constructed at the Central Technical College. In one side it had twelve circular holes cut for observation. These could be plugged up when not in use, and the opaque screen could be placed before any one of the windows. He suggests blocking up the corners of the box with triangular pieces of cardboard or wood, to approach more nearly the spherical shape, but it is not clear from the context whether or not his box was so built. He says: "For demonstration purposes in the lecture theatre the window, covered with tracing cloth, is turned towards the audience and the lamp, blackened on one side, is slowly rotated. It is impossible to tell from the appearance of the window which way the lamp is turned." It is unfortunate that Prof. Howe does not present some photometric data to show accurately the behavior of his integrator under such conditions. Further information regarding such an integrator would be of interest, since it could probably be used for work where comparisons of lamps of the same type are made, or when it is desired to determine the relative efficiencies of the same lamp under different conditions of burning, but where a high degree of precision is not required.

L. W. Wild[22] describes a box integrator 22 in. x 20 in. x 20 in. which he constructed. In various tests, with the lamp in various positions, using different sizes of screens, etc., he got photometric differences of the order of 2½ to 4 per cent. The data which he presents are not sufficient to indicate whether or not it might have been possible to improve his results by taking certain precautions. It seems very probable, however, that a larger box would give better results.

A cubical box measuring 2 meters a side has been installed at the National Physical Laboratory and used for comparing lamps whose distribution curves do not greatly differ from each other.

There is no information at hand to indicate whether or not its operation there has proved satisfactory.

BUREAU OF STANDARDS SPHERE.

During the summer of 1915 a reenforced concrete sphere, 88 inches (2.23 m.) internal diameter, was built at the Bureau of Standards. It differs in so many details from the ones described above that it has seemed desirable to give a description of it. Recently there have been a number of inquiries as to the method of construction, some of which were from persons who contemplated building a similar apparatus. In order to be of the maximum usefulness to such persons the construction of the sphere will be described in some detail, since the small details often give the most trouble in the construction of such an instrument.

The general plan of the sphere is shown in the sketches in Fig. 3. It has sixteen vertical ribs of structural steel T, 1 in. x 1 in. x 1/8 in. (3.17 mm). (The ribs would be better if 3/16 in. [4.76 mm.] thick instead of 1/8 in., as the latter are too flexible. Also, the structural framework should be supported above and below while putting on the expanded metal and applying the cement mortar and plaster, to prevent it from losing the true spherical shape.) The ribs are fastened at top and bottom to steel rings, made up of 2 in. x 1½ in. (5.08 x 3.81 cm.) angle iron, bent and welded in rings of 2 ft. (0.60 m.) diameter. Between each pair of ribs are three steel straps of 1 in. x ¼ in. (6.35 mm.) section, these being fastened with small bolts at each end to the top of the T, and butting up against its web. These are to strengthen the framework and make it rigid. Between the ribs are fastened sheets of expanded metal, cut to fit the spaces and fastened in place by wires passing over the top of the T's, as shown in the sectional sketch.

The body of the sphere is plastered inside and out with portland cement mortar, of the proportions one part cement to two and one-half parts of sand. This was applied to the expanded metal with a curved trowel, and swept out to a true spherical shape by a suitable sweep as shown in the sketch. The sweep was made up of a wooden circular arc fastened to an arm. Steel straps were bolted to this arm, and at the other end they were fastened by a horizontal bolt at the middle point of a vertical section of 2-in. pipe, which passed through holes in boards at the

center of the top and bottom openings of the sphere. Hence the pipe could turn around a vertical axis, and the arm about a horizontal axis, thus allowing the sweep to reach all parts of the spherical surface. The pipe was threaded at both ends and fitted with lock nuts, so that a small adjustment up or down could be made. Provision was also made for a small adjustment of the length of the arm carrying the sweep. The cement surface was scratched, and after drying the walls were coated inside and outside with a mixture of Best Bros.' "Fine" cement with 10 per cent. hydrated lime added. This gives a hard white surface, which can be made as smooth as desired. It is not possible to obtain a pure white surface in this way, however, if a thin coating is used, as grains of the portland cement work up to the surface in applying the white cement. In that case it is necessary to paint the surface later.

The bottom hole of the sphere is covered by a concave metal disk standing on three legs on the floor, so that a space about 1 in. high is left for the admission of air. The top hole is covered by a flat wooden disk let down from above far enough to allow an air space about 1 in. high. It is made up of annular rings, cut in half, and hinged so that any section can be let down, and any section can be entirely removed by drawing out the pin of the hinge. Button latches hold the sections up. By means of this arrangement lamps suspended from an overhead track can be lowered into the sphere after dropping down the proper center sections. If it is desired to have the lamp wholly in the sphere, these sections can be raised again, closing the opening except for a 1-in. hole through which the lamp suspension and wires pass. If it is desired to have only the globe of an arc lamp inside the sphere, the proper center sections can be removed entirely, and, if the mechanism casing does not fill the hole, white paper can be used to complete it.

On one side of the sphere is a hinged door 37 in. (93.9 cm.) high and 16½ in. (41.9 cm.) wide at its widest point. When shut it forms a segment between two adjacent ribs. The hinges used are ordinary 16-in. strap hinges, bent to fit the curved surfaces to which they are fastened. The axes of the hinges are about 3 in. (7.62 cm.) from the sphere surface, and are braced by steel rods passing into the spherical shell. Each rod has two

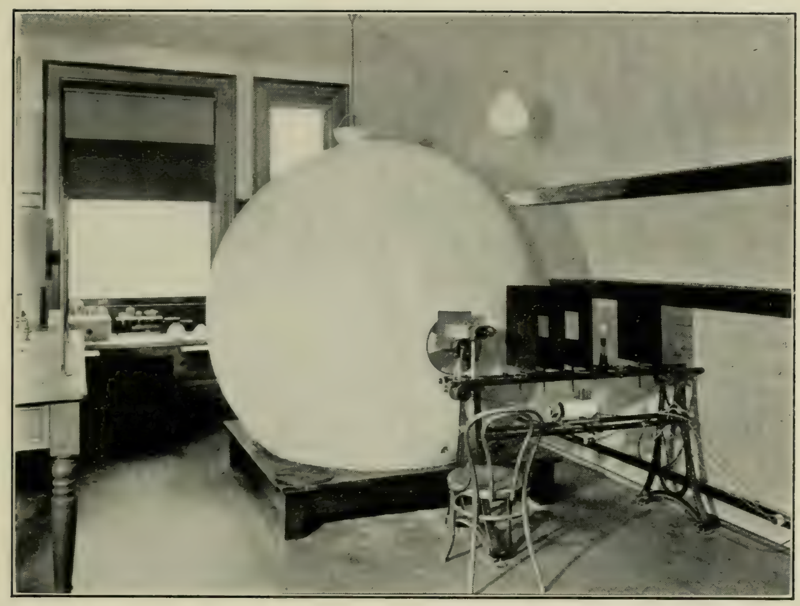


Fig. 1.

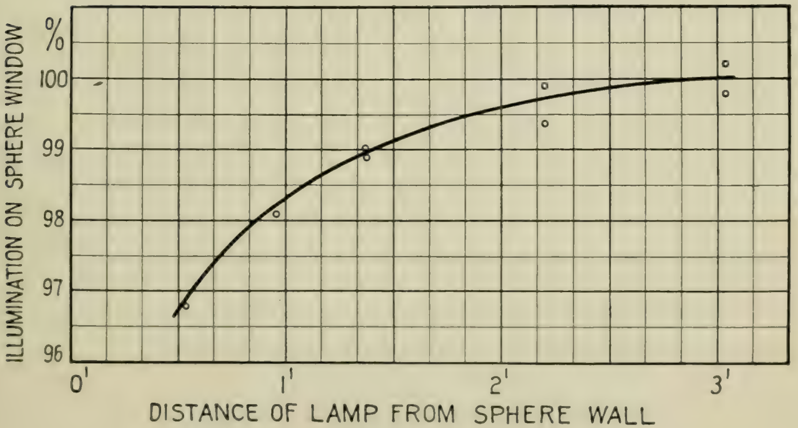

%
100
99
98
97
96
ILLUMINATION ON SPHERE WINDOW
0'
1'
2'
3'
DISTANCE OF LAMP FROM SPHERE WALL

Fig. 2.

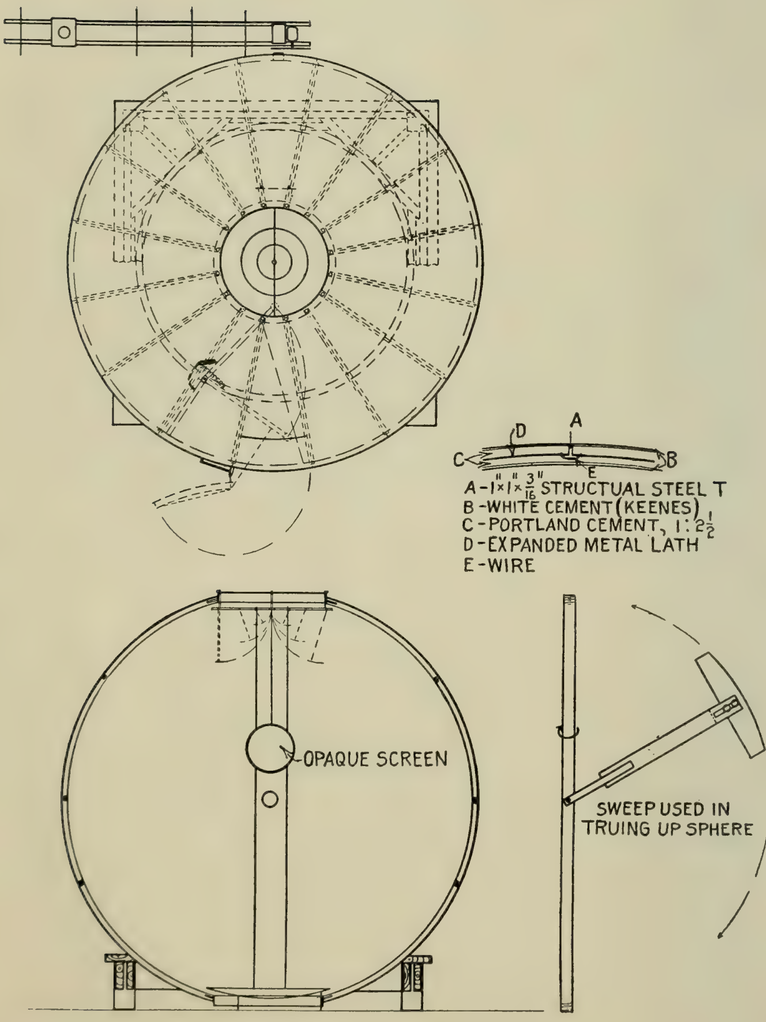

A
D
C
B
E
A-1"×1"×3/16" STRUCTURAL STEEL T
B-WHITE CEMENT (KEENES)
C-PORTLAND CEMENT, 1:2½
D-EXPANDED METAL LATH
E-WIRE
OPAQUE SCREEN
SWEEP USED IN
TRUING UP SPHERE

Fig. 3.

nuts on the end passing through the hinge, so that the hinge can be forced in either direction to take up sag due to the weight of the door.

In the wall directly opposite the door, on the equator, is a brass tube about 3⅛ in. (7.93 cm.) in diameter. Into this telescopes another tube which carries the milk glass window, with proper diaphragms for screening it. The milk glass is flush with the inner surface of the sphere when in use, but can be removed for cleaning.

At a point about 27 in. (68.58 cm.) in front of the window are two vertical rods upon which a runner is moved up or down by a string passing through a small tube in the wall directly above. Four screens of diameters 11, 21, 30, and 38 cm. are provided to be attached to the runner, so that for any lamp the smallest screen usable can be chosen.

The method of introducing the lamp socket into the sphere is unlike any heretofore described. At a point to the left of the door, just above the equator, a section of ½ in. (12.3 mm.) conduit passes into the sphere to a distance of 13½ in. (34.29 cm.) at which point another section about 23 in. (58.42 cm.) long is hinged to it. At the end of this section are two lamp sockets, one above the other, so that lamps can be burned either tip up or tip down. Voltage and current leads are attached to the sockets in parallel, passing through the conduit and around the hinge. A short, stiff, curved rod is attached to the stationary section just behind the hinge, and a spring is attached to this rod and to the movable section. One end of a flexible cord is fastened to the door, and the other end to the conduit near the lamp sockets. When the door is opened the sockets are drawn forward to the opening by the cord to facilitate the change of lamps, and upon closing the door they are drawn by the spring to a point about 10 in. from the center of the sphere. An adjustable reflector holder is provided for use with either socket.

The sphere is supported by a low oak platform. Before applying the cement all ribs were fastened to the platform by heavy screws, so that sphere and platform are rigidly connected.

The question of the proper diffusely reflecting white surface is not yet settled. The zinc oxide on the market is of various grades, some of which are distinctly yellowish, hence it is evident

that if it is used it must be carefully selected. The authors had intended to use the zinc white paint as recommended by Utzinger,[27] but that obtainable was distinctly yellow, and hence could not be used. After inspecting about fifteen samples of so-called "flat white" paints, none of which proved to be pure white, it was decided that the Keene's cement used in surfacing the sphere was the whitest substance available at that time. Two thin brush coats were applied, allowed to dry, and then sandpapered. Tests made to determine whether or not there was selective absorption indicate that the absorption is somewhat selective, so that the reflected light is perceptibly yellowish when compared with the direct light from the lamp tested. While this surface is probably nearly enough non-selective to introduce no serious errors, further experiments will be carried out to find a better paint, and it is hoped that a satisfactory selection can be reported at some future time. As will be noted later, this cement has a very high reflecting power, hence is excellent for the purpose, but it is essentially a cement, not a paint, and therefore cannot be applied to all surfaces as a paint.

The photometric equipment consists of a 1.5 meter standard photometer bar, equipped with screens, lamp carriage, sectored disk, recording drum, and printing magnet and a special contrast type photometer head. The photometer head is arranged so that the window of the sphere forms one side of the photometric field, and a milk glass illuminated by the comparison lamp forms the other side. The comparison lamp is shifted by a belt and pulley arangement which is operated by a wheel near the photometer head. Photometer settings are recorded on a sheet of paper on the drum in the usual way by the pressure of a button in series with the electromagnet. Electrical adjustments of test and comparison lamps are made by suitable rheostats and a deflection potentiometer.

The cost of the sphere as constructed can be given only approximately, since no record was kept of the time spent in its construction by the men in the laboratory. The platform was built outside the Bureau, and the plastering was done by a skilled plasterer. The cost of the materials in the completed sphere and platform, including the shaped structural steel, was about $75.00, and the cost of the labor was about as much more aside from

the work done by the laboratory assistants. The cost to anyone building a sphere similar to this would depend largely on the planning and supervision, as well as the facilities at hand for doing the work, but under favorable circumstances it ought to be built for between $200 and $300, according to the cost of labor, if new plans were not made, not allowing for the expense of supervision.

Since this sphere differs in many ways from others in present use, it seems desirable to consider its advantages and disadvantages. Most of the large spheres are divisible into halves, one of which is on rollers, so that they can be separated for adjustment of arc lamps, etc., in the sphere, and for cleaning and painting. This sphere, while not divisible, is almost as convenient, on account of the subdivided top section, and avoids the necessity for a track which takes up valuable floor space. In order to work on the inner surface of the sphere the bottom section can be lifted out and by means of a step ladder the operator can step into the sphere and stand on the floor beneath the bottom opening, from which point he can easily reach any part of the spherical surface.

The sphere is rigid and substantial in construction, has a good surface, continuous (except for necessary openings) and truly spherical, easily repaired or renewed if necessary, and is well ventilated. It is not, however, portable.

In operation the sphere has been found to possess distinct advantages due to the use of two sockets for burning lamps either tip up or tip down and the arangement for drawing the lamps near to the sphere center, the use of an adjustable shade holder, good ventilation, and the use of a standard photometer bar and its accessories.

TESTS OF BUREAU SPHERE.

The principal tests of this sphere which we have made were for the purpose of determining the accuracy of integration of sources of different types. For this purpose distribution measurements of various sources were made on a two-mirror selector, and calculated values of mean spherical candlepower were obtained. These sources were then placed in the sphere and further measurements were made. In all measurements with both photometers the bare lamp flux was taken as 100 per cent. The re-

sults are shown in Table I, in which the values shown refer to the percentage of bare lamp flux for the lamp used in each case.

TABLE I.—COMPARISON OF INTEGRATION BY DISTRIBUTION PHOTOMETER AND INTEGRATING SPHERE.

Source	Distribution photometer		Integrating sphere	Per cent. difference
Lamp No. 1 in reflector No. 1	65.7	Tip up	65.7	0.0
		Tip down	65.3	—0.6
Lamp No. 2 in reflector No. 2	86.3		86.8	+0.6
" " " " " 3	84.3		85.0	+0.8
" " " " " 4	89.6		91.1	+1.7
" " " " " 5	81.2		80.4	—1.0
" " " " " 6	87.6		87.3	—0.3
Lamp No. 1 in 12-inch globe No. 1	80.2		80.5	+0.4
" " " " " " 2	76.1		76.5	+0.5

Lamp No. 1, 100-watt tungsten, clear.
" " 2, 40 " " , bowl-frosted.

Reflector No. 1, porcelain enameled reflector, total flux in lower hemisphere.

Reflector No. 2, Holophane prismatic, satin finish.
" " 3, light density opal, "Lucida."
" " 4, " " alba, flaring type.
" " 5, Heavy density opal, "Pheno."
" " 6, Holophane prismatic, clear, extensive.
Globe " 1, 12-inch opal globe, polished, "Polycase."
" " 2, 12-inch " " depolished, "Alabastine."

The agreement of the values obtained in the two ways is good, except perhaps for reflector No. 4. The distribution photometer measurements are difficult, on account of the low intensity of the light at many angles (photometer distance was about 10 ft.) (3.04 m.) and the error is probably greater in those measurements than in the spherical photometer.

In order to measure the absorption, by various black objects, of light diffusely reflected from the sphere wall, several test objects were made up. Lamp No. 1 was burned tip down in reflector No. 1, and the test object was suspended near the center of the sphere, where no direct light could fall on it. The results are shown in Table II. Where the test object is designated as "single disk," it was a black cardboard disk fastened to one face of the opaque sphere screen. The term "double disk" refers to a disk blackened on both sides. The absorption values shown in the table indicate the amount by which the sphere window illumi-

nation was reduced when the objects were suspended in the sphere, so placed as to be screened from the sphere window.

TABLE II.—ABSORPTION OF REFLECTED LIGHT BY VARIOUS BLACK OBJECTS.

Object	Area (cm^2)	Per cent. of sphere area	Per cent. absorption	Absorption ÷ relative areas
Single disk	1,146	0.729	7.1	9.7
Cube	1,104	0.702	7.1	10.1
Cylinder	1,118	0.711	6.75	9.5
Double disk.......	1,078	0.686	6.8	9.9
Single disk	539	0.343	3.0	8.8
" "	181	0.115	0.9	7.8

The results apparently indicate that the absorption of reflected light by black objects in this sphere is independent of their shape, and that the absorption factor is 9.5 to 10 times the proportional area for objects of the size tested. The last two objects in the table seem to indicate a smaller proportional absorption for smaller objects, though this is not certain, since the calculations carried out are very severe tests of the accuracy of the data.

In the same way the amount of reflected light absorbed and obstructed by the opaque screens provided for the sphere was tested. The results are shown in Table III. The absorption values in this table have the same meaning as in Table II.

TABLE III.—ABSORPTION AND OBSTRUCTION OF LIGHT BY OPAQUE, WHITE SPHERE SCREENS.

Area of screen	Per cent. of sphere area	Per cent. absorption	Absorption relative areas
197 cm^2.	0.125	0.1	0.8
692	0.440	1.4	3.2
1,414	0.900	3.3	3.7
2,292	1.458	5.2	3.6

These values, with the exception of the first, indicate that the absorption is directly proportional to the relative areas of screen and sphere surface. The screens are not quite as white as the sphere surface, and these absorption values can probably be lowered somewhat when a whiter paint is obtained.

A test to determine the amount of absorption of reflected light by clear lamps of sizes from 50 watt gem to 250 watt tungsten indicated absorptions so small as to be uncertain within the error of measurement, and hence negligible.

A test of the effect of the lamp position was made, and results are shown in Fig. 2. The points shown are for a 100-watt lamp, bare.

The results were almost identical for tests of the bare lamp with two sizes of sphere screens, 21 and 38 cm. diameter, and for the lamp in the enameled reflector No. 1. While the results for the bare lamp might be explained on the theory that as the

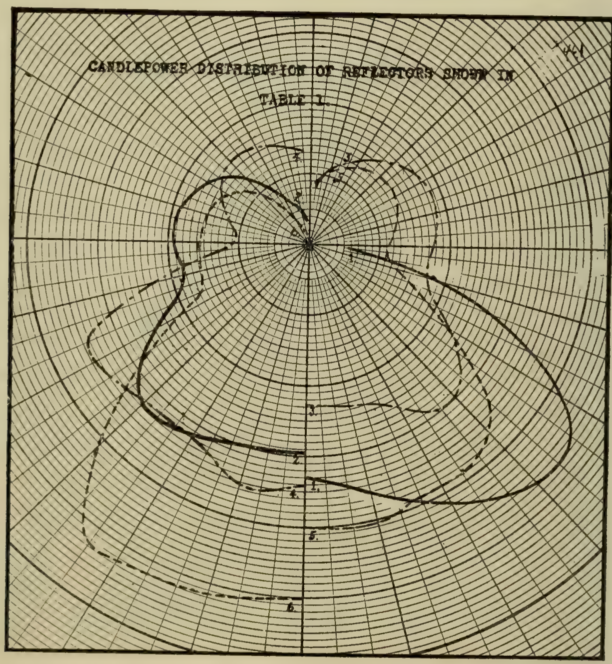


Fig. 4.

lamp approaches the sphere wall a greater amount of the lamp flux falls on the screened area, the same explanation does not hold when the lamp is in the reflector. Hence the reason for the observed differences is not clear.

The differences in sphere window illumination when an asymmetrical source was pointed in different directions was also tested. For this test a parabolic metal reflector, with the parabolic axis perpendicular to the lamp axis, was used. The results are shown in Fig. 5, the radical lines showing the direction of maximum

flux, *i. e.*, the direction at right angles to the plane of the reflector face. The values inside the circle were obtained with the regular milk glass window, while the values outside the circle were obtained when a clear ground glass window was substituted.

A test to determine the reflecting power of the sphere walls was made. For this test the window was removed from the sphere wall, placed on the photometer bar, and a portable photometer

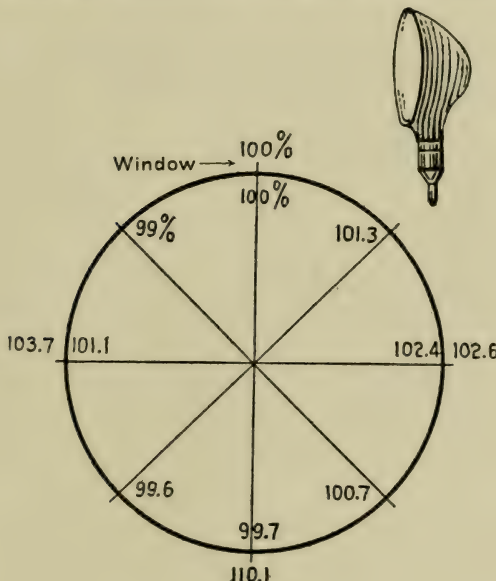


Fig. 5.

pointed at it. A standard lamp was arranged at a measured distance from the milk glass, and the photometer standardized to measure the illumination on the window. The window was then replaced, and the illumination on the window measured when the same standard lamp was burned in place in the sphere.

Three measurements of illumination were made, *viz.*, with window screened, window unscreened, and screen removed from sphere. From these measurements the amount of direct illumination thrown on the window by the lamp alone was determined, and this was subtracted from the illumination value obtained when the screen was removed from the sphere. These measurements indicated that the window illumination by reflected light

only is 67.8 foot-candles when a lamp of 80.7 mean spherical candles is burned in the sphere. The calculation of light absorption by the sphere walls is then as follows:

Let

E = average illumination on sphere wall.

E_d = average direct illumination $= \dfrac{\text{m. s. cp.}}{(\text{radius})^2}$.

E_r = illumination by reflected light

E_m = measured illumination $= E - E_d = E_r$

r = reflection coefficient

a = absorption

$$E = \frac{E_d}{1 - r} = \frac{E_d}{a} = E_d + E_m$$

$$a = \frac{E_d}{E_d + E_m}$$

The various factors are these:

M. s. cp. = 80.7, $(\text{radius})^2 = (3\tfrac{2}{3}\text{ ft.})^2 = 13.44\text{ ft.}^2$

$$E_d = \frac{80.7}{13.44} = 6.0 \text{ foot-candles}$$

E_m = 67.8 foot-candles

$$a = \frac{6}{6 + 67.8} = 8.1 \text{ per cent.}$$

These measurements indicate a very high reflecting power, in fact the value was so high that the above experiment was repeated with similar results. The reflection from a disk of similar material was later measured by another method, and this result was confirmed.

METHODS OF MEASUREMENT.

In the measurement of the reflectors shown in Table I the method of test was as follows: The bare lamp was put in one socket and a reading taken. The reflectors were then successively placed on the other socket, without lamps, and other readings taken. The relative values of the two readings give the allowance to be made for the absorption of reflected light by each reflector. Next, the reflectors were successively placed on the socket where the bare lamp formerly was, the lamp placed in the reflector, and more readings taken. These readings were then worked up as

percentages of the readings with bare lamp, and the proper allowance made for absorption of reflected light by the reflector.

In the tests of the opal globes the standard lamp was placed in the sphere, tip up, and screens arranged to screen from the photometer window the direct light from the lamp and globe. Readings were then taken *without* the opal globe in the sphere. Next a cap was placed on top of the standard lamp to screen from the globe the direct light from the standard lamp, and another reading taken, still without the globe in the sphere. Then the globes were successively lowered into the sphere from above, and more readings taken.

The differences between the readings under the last two conditions give the allowance to be made for absorption of reflected light by the globes, which was about 4 per cent. The standard lamp was next placed within the globes successively, and readings taken with the globes about 6 in. below the top of the sphere. These readings, expressed as percentages of the reading with the bare lamp in the empty sphere, after the allowance for absorption of reflected light is made, are the values shown in the table. Tests made without screening the globes from direct light from the standard lamp gave values in error by over 2 per cent.

SOURCES OF ERROR.

There are a number of recognized sources of possible error in the use of the sphere, the most important of which are probably as follows:

Mixed diffuse and specular reflection from sphere surface.

Selective absorption by paint.

Inequalities of reflection from sphere walls.

Imperfect diffusion of milk glass window.

Presence of foreign objects.

Necessary use of screens.

Position and orientation of lamps in sphere.

Absorption of direct light flux from standard lamp by test lamp.

E. Dyhr,[23] at the suggestion of Ulbricht, investigated some of these. He states that although by a suitable mixture of zinc white and other materials an initial very white coating can be secured, these surfaces tend to become yellow and selectively re-

flecting with age. By the use of red and green screens he investigated the extent of the possible error, and found that it is possible to make an error of about 2 per cent. in comparing carbon lamps with metallic filament lamps, but that this error increases much less quickly than the color differences. He next considers the incomplete diffusing character of the opal glass window, and finds that this complies with the inverse-square-law within 2 per cent. He also describes, with diagrams, tests on the degree of mattness of the kind of surface used in globe photometers, and finds the error due to incomplete fulfilment of the theoretical requirements in this respect is only 0.8 per cent. The error due to lack of uniformity in absorption, as distinguished from a mixture of diffusion and direct reflection, is also stated to be of small consequence. He expresses his opinion that adequate accuracy is sacrificed when departure from the spherical shape is made.

Ulbricht[20], in discussing a paper by Sumpner, states that moderate deviations of the reflecting power of the paint from the cosine law are of very little consequence in practise. He thinks that the presence of foreign objects in the sphere, such as screens, etc., need exert very little influence on practical results in globes of the prescribed dimensions. He states that if a suitable milk glass window, obscured on the *inside* is selected, any deviation from complete diffusion would give only trifling errors, as the surface illuminating it is very extensive. He says that the window could be removed and the photometer sighted at the opposite sphere wall.

To test the effect of an imperfectly diffusing glass window, the authors replaced the milk glass window in the Bureau sphere with a clear glass disk ground on both sides. The value obtained for reflector No. 1 (the porcelain enameled reflector) in Table I, using the ground glass window, was too low by 2 per cent. Another test was carried out with the asymmetrical source used in the previous test with the milk glass window. When the most intense flux was directed at the wall 90° from the window, the relative readings were higher than those for the milk glass by about 1 per cent. With the flux directed at the wall directly opposite the window the ground glass window gave a value 10

per cent. higher than that given by the milk glass. These tests indicate that the window must be made of a much better diffuser than clear ground glass, but from the other tests which we have made the milk glass appears to be perfectly satisfactory.

As regards the use of screens, it is apparent from the theory that one should select the smallest screen which will completely screen the window from the test source, and locate the screen so that it will most effectively perform this function.

The question of relative advantages of translucent and opaque sphere screens was treated in Chaney and Clark's[25] paper before this society, and in the discussion afterwards. Only opaque screens have been used in this sphere.

A test of the effect of position of the lamp on the window illumination was described earlier, and results shown in Fig. 2. It is of special interest to note that when the reflector measurements in that test were worked up for each position in terms of the standard lamp readings for the same position, the values were as follows: 66.2, 66.3, 66.4, 66.2, 66.2 per cent. (This was not the lamp used with this reflector in the tests shown in Table I.) This indicates that when the substitution method was employed the final results were independent of the lamp position.

Bloch[7], Winkler-Buscher[18], and others state that from both theory and tests they find that the illumination on the window is independent of the lamp position. Perrine[17] found differences, but they are so large that it seems probable that they were not altogether due to the causes which he was investigating. Apparently no other investigators have found such large differences.

One use of the sphere which has received a great deal of attention abroad, but apparently has not been investigated in this country, is the measurement of mean lower hemispherical candlepower. Ulbricht,[3,4] Monasch,[6] Bloch,[11] Corsepius,[15] Winkler-Buscher[18] and others have described the use of the sphere in that connection.

We have not, however, investigated the use of the sphere for this purpose.

In conclusion, it may be stated that the instrument here described has proven very satisfactory during the short time it has

been in use, and promises to be a very considerable addition to the photometric equipment of the Bureau.

The authors are indebted to Mr. E. C. Crittenden for many helpful suggestions, and to Messrs. G. J. Schladt, and M. Hertz for assistance in the construction of the sphere described.

BIBLIOGRAPHY.

1. The Diffusion of Light. Sumpner.
   Philosophical Magazine, 1893.
2. Photometer for Mean Spherical Candlepower. R. Ulbricht.
   Elektrotechnische Zeitschrift, 21, p. 595, 1900.
   Science Abstracts, 3, ¶ 2154, 1900.
3. Globe Photometer. R. Ulbricht.
   Elek. Zeit., 26, p. 512, 1905.
   Sci. Abs., 8, ¶ 1160, 1905.
4. Measurement of Mean Hemispherical Intensity by Means of a Globe Photometer. R. Ulbricht.
   Elek. Zeit., 27, p. 50, 1906.
   L'Eclairage Electrique, 46, p. 432, 1906.
   Sci. Abs., 9, ¶ 370, 1906.
5. Ulbricht's Globe Photometer. M. Corsepius.
   Elek. Zeit., 27, p. 468, 1906.
   Illuminating Engineer (New York), 1, p. 482, 1906.
   Sci. Abs., 9, ¶ 772, 1906.
6. Auxiliary Apparatus for Determining Mean Spherical and Hemispherical Candlepower. Dr. B. Monasch.
   Elek. Zeit., 27, pp. 669, 695, 803, 1906.
   Illum. Eng. (New York), 1, pp. 586 and 700, 1906.
   Sci. Abs., 9, ¶ 1233, 1906.
7. Practical Value of Ulbricht's Globe Photometer. L. Bloch.
   Elek. Zeit., 26, pp. 1047 and 1074, 1905.
   Illum. Eng. (New York), 1, p. 421, 1906.
   Sci. Abs., 8, ¶ 1688, 1905.
8. Theory of Ulbricht's Globe Photometer. E. Presser.
   Elek. Anzeiger, 23, pp. 885 and 912, 1906.
9. Globe Photometer. R. Ulbricht.
   Elek. Zeit., 28, p. 777, 1907.
   Sci. Abs., 10, ¶ 1086, 1907.
10. Ulbricht's Globe Photometer. E. Winkler.
    Schweizerische Elek. Zeit., 4, pp. 85, 97, and 110, 1907.
    Sci. Abs., 10, ¶ 437, 1907.
11. The Globe Photometer in Practical Photometry. L. Bloch.
    Illuminating Engineer (London), 1, p. 274, 1908.
12. Modern Photometrical Appliances.
    Illum. Eng. (London), 1, p. 228, 1908.

13. On the Theory of the Globe Photometer.
Illum. Eng. (London), 1, p. 553, 1908.
14. The Integrating Sphere in Industrial Photometry. Sharp and Millar.
Trans. I. E. S., 3, p. 502, 1908.
Illum. Eng. (London), p. 1031, 1908.
15. Measurement of Mean Hemispherical Candlepower by the Ulbricht Globe. M. Corsepius.
Illum. Eng. (London), 1, pp. 801 and 895, 1908.
16. The Center of Intensity of a Light Source. R. Ulbricht.
Elek. Zeit., 30, p. 322, 1909.
Sci. Abs., 12, ¶ 490, 1909.
17. Experimental Study of the Globe Photometer. A. A. Perrine.
Electrical World, 54, p. 727, 1909.
18. The Ulbricht Sphere for Measuring Mean Spherical Candlepower. E. Winkler-Buscher.
Elektrotechnik u. Machinenbau, 28, p. 659, 1910.
Sci. Abs., 14, ¶ 120, 1911.
19. The Determination of Mean Spherical Candlepower. By an Engineering Correspondent.
Illum. Eng. (London), 3, p. 265, 1910.
20. The Direct Measurement of the Total Light Emitted from a Lamp. W. E. Sumpner.
Electrician (London), Apr. 22, 1910.
Illum. Eng. (London), 3, p. 323, 1910; Discussion, p. 387.
21. Photometric Units and Nomenclature. E. B. Rosa.
Bureau of Standards Bulletin 6, p. 560, 1910.
22. The Box Integrating Photometer. L. W. Wild.
Illum. Eng. (London), 3, p. 549, 1910.
23. Errors in the Ulbricht Globe Photometer. E. Dyhr.
Elek. Zeit., 31, p. 1295, 1910.
Sci. Abs., 14, ¶ 128, 1911.
24. Globe Photometer. E. W. Marchant.
Illum. Eng. (London), 4, p. 37, 1911.
25. Notes on the Integrating Sphere and Arc Lamp Photometry. Chaney and Clark.
Trans. I. E. S., 10, p. 1, 1915.
26. Integrating Sphere Equipped for Testing Gas-filled Lamps.
Elec. World, p. 120, Jan. 9, 1915.
27. Paint for Integrating Spheres. A. Utzinger.
Elek. Zeit., 36, p. 137, Mar., 1915.
Sci. Abs., 18, ¶ 724.

DISCUSSION.

Mr. E. L. Clark (Communicated): The work reported in this paper is done with the painstaking care and thoroughness which we have become accustomed to find in work turned out at the Bureau of Standards. The test results show that the Bureau has a remarkably fine sphere. The results on the reflecting coefficient of the sphere wall were particularly surprising. It is very much higher than I had thought could practically be obtained. On the fourteenth page in commenting on the results shown in Fig. 2 on "change in lamp position," it is stated that in the case of a lamp in the reflector, the reason for the falling off in the reading as the lamp is brought nearer the sphere wall is not clear. A satisfactory explanation for this is as follows: As the lamp is brought nearer the sphere wall, the direct illumination, on the portion of the surface approached, increases. Also the solid angle intercepted by the reflector from a point on this surface of increased brightness increases. Consequently the reflector is intercepting more of the first reflected light flux, and therefore absorbing more and lowering the reading. I have observed this same effect when bringing a light source in a large diffusing globe near the screen used to shield the window, and the same explanation applies. In general, it can be said that if a light source has associated with it parts having an appreciable light absorption, the reading of the photometer will be lowered when the light is moved nearer to the reflecting surface of the sphere, apart from the effect of change in the ratio of flux on the screened and unscreened areas, the two actions must be considered separately.

The high reflecting surface of the sphere described will permit measuring small light sources with precision. A further use for the sphere, which I believe will attain some importance, is in the measure of the total flux of rather concentrated beams.

The absorption of projector lenses can easily be measured in this manner.

Dr. N. K. Chaney (Communicated): The authors are to be congratulated upon having constructed a notably superior spherical integrator. The manner in which the results obtained with this instrument check with the theoretical treatment and experi-

mental data in our own paper [25] is very gratifying. This establishes the possibilities of the sphere as a precise photometrical instrument beyond question. The most striking feature in the paper is the reduction of the 20 per cent. absorption coefficient (the usual approximate value for mat white surfaces) to a value of 8 per cent. by the use of a special surface finish. At one stroke this lessens the possible discrepancies in integration by over 50 per cent., since, as we have shown, the integrating error is the product of three factors: (1) the absorption coefficient, (2) the screen coefficient (*i. e.*, the ratio of screened areas to the total area) and (3) the difference in the percentage of the light flux from the standard source and the unknown source respectively, which falls upon the screened areas. Thus, the reduction of any one of these three factors means a corresponding reduction of the maximum possible integrating errors. If any one of these factors approaches zero the total error is correspondingly negligible. Thus, referring to the middle of the nineteenth page, the reduction of the reflector readings for different positions by the standard lamp readings for the corresponding positions, gave closely concordant results because the third factor in the integating formula above approached zero for these positions. The method of measuring the absorption coefficient is essentially the same as that employed by us in determining the relative effects of extended light sources. It would be of interest to know how well the method of measuring the absorption coefficient suggested by the theory of the screened areas would agree with the values found by the authors. This method consisted in rotating a beam of light so that it fell, first, entirely within the screened area opposite the test plate and, second, entirely within the unscreened area at right angles to the test plate. The per cent. difference in the photometer readings for these two positions should be the absorption coefficient or 8 per cent., if our sphere analysis is correct. The behavior of the milk glass and ground glass test plates is in perfect agreement with the theory and shows why in the sphere analysis it is convenient to treat the multiple reflections as primary light fluxes; for example, on the second page, the illumination is divided into two parts, (*a*) that due to the primary source, and (*b*) the multiple reflections of (*a*). Now it is necessary to distinguish between the first of the multiple reflections of (*a*) which

may be designated b and which is asymmetric in character and the subsequent multiple reflections of (a) or b_2 which are symmetrical in behavior. That is b is divided into two components, b_1 and b_2, of which b_1 is the erratic and troublesome member. Now consider Fig. 5; when the light source is directed toward the test plate, the source of b^1 (the first multiple reflection) is situated in part as a bright band around the test plate. Its flux strikes the test plate at a very oblique angle. When the light source is directed to the opposite side of sphere the source of b^1 is (so far as the test plate is concerned) the brightly illuminated ring visible at the back of the sphere from the test plate. Hence the part of its flux reaching the test plate is more nearly normal. Now while the flux falling on the test plate is the same for any given bright patch, irrespective of its position on the sphere walls, the amount of this flux which is transmitted may vary with the angle of incidence of the flux, and does so vary to a marked degree with the ground glass surface. The area near the test plate registers less than its proportional value on the photometer, because of this excessive reflection of the ground glass surface for oblique rays. Hence as shown in Fig. 5, the readings with the ground glass plate successively diminish as the light is rotated from the back of the sphere around toward the test plate. The transmission of light by the milk glass test plate is evidently much less dependent upon the angle of incidence, that is it more nearly obeys the cosine law. Hence in the latter case the influence of the screened areas predominates and the readings are higher at the two side positions where less light falls upon the screened areas than when the light is directed toward or opposite to the test plate. The values found with the ground glass plate are a composition of the screen effect as shown by the inner readings, and the effect of the departure from the cosine law of the ground glass plate, the two working in opposition at the side positions. It might be noted in Table II that the ratio of the absorption factor to relative areas of the sphere and the absorbing body is at a maximum in the center of the sphere and that as the black object is moved toward the sphere wall this ratio will approach unity; that is, at the sphere wall the per cent. absorption will be approximately equal to the ratio of the relative areas when corrected by the reflection coefficient of the black body.

MR. R. B. CHILLAS, JR. (Communicated): In reference to measurement of the mean hemispherical candlepowers, a further use of the principles of the integrating sphere is in the measurement of the effective light flux within a given solid angle. This is directly applicable to searchlight work.

The useful light for such work is only that which falls within the solid angle subtended by the parabolic reflector about the light source; this angle is usually 120°. The method and apparatus used to measure the useful flux from a searchlight lamp is as follows: A sphere divided vertically into two hemispheres, an auxiliary high powered incandescent lamp, mounted in an opaque backed reflector to give its total flux in one hemisphere, and a standard lamp. With the sphere closed, determine the mean spherical candlepower of the lamp in its reflector. Open the sphere, remove the screen and substitute a small screen so placed as to cut off from the window only the direct light from a source placed on the horizontal axis, but none of the reflected light from the rim of the hemisphere. Mount the auxiliary lamp on the horizontal axis of the hemisphere, so that all of its light falls within the hemisphere, and read the photometer. Then remove this lamp, mount the searchlight lamp mechanism in such a position that the rim of the hemisphere will subtend the same solid angle about the light source; for example, the positive crater of the arc, as would be subtended by the rim of the parabolic reflector when the lamp is in use. Read the photometer.

From these readings, namely the total flux from the auxiliary lamp, the mean illumination produced by it on the hemispherical surface, and the corresponding value for the searchlight lamp, the total useful flux within the effective solid angle subtended by the searchlight mirror may be calculated, thus:

$$\begin{array}{c}\text{Effective scp. of}\\ \text{searchlight}\end{array} = \text{scp. of auxiliary} \times \frac{\text{Illumination from searchlight}}{\text{Illumination from auxiliary}}.$$

The value given by this equation is in terms of scp. falling on the mirror; this may be converted to mean effective candlepower by multiplying by the factor $\frac{2}{1-\text{Cos}\frac{\theta}{2}}$, the ratio of the total sphere area to that within the effective solid angle θ. This

method is given briefly under the discussion of Lt. McDowell's paper on searchlights in the December, 1915, *Proceedings* of the A. I. E. E.

A further possibility in the use of the sphere as described above is the determination of distribution curves. Illumination calculations usually deal with the flux falling within a given zone. Mounting the lamp to be tested at different positions along the axis of the hemisphere and reading the photometer will enable one to determine the total flux within the solid angle subtended by the rim of the hemisphere. The following table shows the distances of the lamp from the rim of the hemisphere and the zones subtended at each point where r is the sphere radius.

Zone	Lamp position
0–30°	1.732 r from rim
0–45°	1.0 r from rim
0–60°	0.577 r from rim
0–75°	0.268 r from rim
0–90°	0.0 r in plane of rim
0–105°	—0.268 r (within rim)

For any zone then the flux is given by the difference between that for any two successive zones.

Mr. D. C. Herrick: The absorption of reflected light by various black objects, (data shown in Table II) is pertinent to a problem in life testing incandescent lamps on a spherical candle-power basis. Using a substitution method of check-up, where the working standard would have a clear bulb, measurement of a lamp with a bulb appreciably darkened would practically involve introducing a black object into the sphere. An error would then exist equal to the amount of reflected light absorbed.

The following equation was theoretically developed to show the amount of this error.

Per cent. error $= 100 - 100\frac{(1 - r)}{(1 - Kr)}$ where r is the reflection coefficient of the sphere wall and $K = 1 - d\frac{a}{A}$; d being the absorption coefficient of the object and $\frac{a}{A}$ the ratio of the area of the object to the area of the sphere.

Application of this equation to the data of Table II gives results 0.5 per cent. higher than those experimentally determined.

Analysis of the test would show the reason for at least part of this difference.

Considering a rather extreme case of photometering a lamp with an eight inch G bulb which is uniformly blackened to an absorption of 20 per cent. shows errors of about 1.0 per cent. with a 100-in. sphere having an 80 per cent. reflection coefficient, 3 per cent. with a 54-in. sphere and 5 per cent. with a 42-in. sphere. Apparently this source of error must be considered where accurate results are desired.

MR. A. H. TAYLOR (In reply): One speaker has shown us some spectro-photometric curves of light reflected from painted surfaces. I would like to point out the fact that spectral curves of light reflected only once are of little value, since the small differences are multiplied many times when the paint is used in a sphere. If, however, the measurements are made on the light emerging through the sphere window they are of value. In our work to determine a suitable paint we made up a rectangular box, with removable walls. Cardboard painted with the test paint was fastened to the inner walls. In one side of the box was a small hole, through which light could shine on a photometer screen, and a lamp socket was placed in the bottom of the box, out of view of the window. Two lamps were color matched on the bar photometer, then one of them was put in the box and burned at the same voltage as before. If a color difference is found, the comparison lamp voltage can be altered to obtain a color match. This method gives results comparable to those obtained when the sphere is painted with the test paint, and is of great value if many samples are to be tested. Only a few paints have been tested as yet, but we hope to make more tests soon.

Another speaker criticised our paper for mentioning the box photometer used at the National Physical Laboratory. We did not intend that to indicate that they considered it an instrument of precision, or as a recommendation of the box photometer, but merely as an interesting fact. As stated in our paper, I think it might serve a useful purpose where precision is not necessary, or where funds are not available for a sphere. The box could be made to approach much more closely the spherical shape by rounding out the corners with cement.

Mr. Clark spoke of the high reflecting power we found for our sphere surface. The result was a great surprise to us too, as we understood that no surface reflected more than about 88 per cent. of the incident light. Three measurements like the one described gave substantially concordant results. To get a further check on the value we made up a 7-in. (17.78 cm.) circular disk of the pure cement, and sandpapered it to a plane mat surface. A photometer was carefully standardized for surface brightness measurements. The disk was mounted on a motor shaft and rotated, and the surface brightness at every 10° was measured when light from a standard lamp of about 4 wpc. color was incident normally on the disk. The reflected light flux was then calculated. Four such measurements, including three separate standardizations of the photometer, gave an average reflection coefficient of a little over 94 per cent., the range of results being about 1 per cent. The measurement of window illumination probably gives a reflection coefficient somewhat too low, since some light gets out of the sphere around the top and bottom plates. (Since this paper was presented another coat of the cement has been applied to the sphere surface, and another measurement of sphere window illumination gives an absorption value of 7.5 per cent. A measurement of the absorption by the method suggested by Dr. Chaney, *viz.*, directing a narrow beam of light first at the screened area opposite the test plate, and second, entirely within the unscreened area, gave a result in very close agreement with the previously determined value of 7.5 per cent.)

Someone asked a question regarding the amount of selective absorption found. A somewhat rough determination showed that if two lamps are color matched at about 115 volts, at an efficiency of about 1.1 wpc. and one of them is introduced into the sphere, the lamp outside the sphere must be reduced to about 89 volts, or an efficiency of about 1.9 wpc. to obtain a color match. While these differences may seem rather large, I believe they are less than would be found in many of the spheres in use to-day. Since the reflecting power of the sphere surface is about 92.5 per cent., it is evident that the selective absorption cannot cause a very large error in results.

TRANSACTIONS

OF THE

Illuminating Engineering Society

NO. 3, 1916

PART II

Miscellaneous Notes

Council Notes.

A meeting of the Council was held March 17, 1916 in the offices of Dr. George S. Crampton, 1700 Walnut St., Philadelphia, Pa. Those present were: Chas. O. Bond, H. Calvert, Geo. A. Hoadley, Clarence L. Law, C. A. Littlefield, general secretary; J. L. Minick, J. Arnold Norcross, and G. Bertram Regar representing Joseph D. Israel. Dr. Geo. S. Crampton, Prof. C. E. Clewell, and Prof. C. F. Scott were present upon invitation.

The meeting was called to order at 2.40 p.m. by Vice-president Geo. A. Hoadley in the absence of President Charles P. Steinmetz.

The minutes of the February meeting were adopted as printed.

A report was received from the Board of Examiners approving the election of three applicants to associate membership and the transfer of one applicant to the grade of member.

Upon recommendation of the Finance Committee, payment of vouchers Nos. 2415 to 2420 inclusive, and Nos. 2425 to 2451 inclusive, aggregating $2,198.70, was authorized. The committee also reported that the disbursements for the first five months of the present fiscal year totaled $7,604.37, while the cash receipts for the same period were $7,594.58.

It was voted to increase the appropriation for the mid-winter convention from $500.00 to $594.00; and the appropriation of the Membership Committee from $70 to $100.

Progress reports were received from the following committees: 1916 Convention Committee, Mid-winter Convention Committee, Administration Committee on Lectures, and Membership Committee.

Oral reports on section activities were made by the following vice-presidents: Clarence L. Law representing New York Section; Geo. A. Hoadley, Philadelphia Section; J. L. Minick, Pittsburgh. A written report was received from Mr. F. A. Vaughn, Vice-president of the Chicago Section.

The following committee appointments were confirmed:

Sub-committee on Finance of the Administrative Committee on Lectures: Wm. J. Serrill, chairman.

Sub-committee on Exhibits of the Administrative Committee on Lectures: Chas. O. Bond, chairman.

Sub-committee on Office Lighting of the Committee on Popular Lectures: Mr. C. D. Fawcett, E. J. Dailey, G. A. Hoadley.

Sub-committee on Elementary Lectures of the Committee on Popular Lectures: G. A. Hoadley, M. Luckiesh.

Sub-committee on Residence Lighting of the Committee on Popular Lectures: J. D. Lee, H. T. Spaulding.

Resolved, that it is the sense of the Council that a meeting in Boston is justified and that the April meeting be held in that city on the 13th proximo.

A letter was read by the General Secretary from Mr. Langan submitting his resignation as Assistant Secretary, to take effect on May 15, 1916.

On motion Mr. Langan's resignation was accepted with regret and the General Secretary was instructed to communicate this information to Mr. Langan. He was also instructed to express to Mr. Langan the appreciation of the Council for his faithful work during the six years he has occupied that office, for the very excellent way in which he has systematized the General Office routine and conducted the general work of the society.

A vote of thanks was tendered to Dr. Crampton for courtesies in connec-

tion with the use of his office for the meeting.

Section Meetings.

CHICAGO SECTION

April 21, 1916, in the Commonwealth Edison Building, 125 So. Clark St., Paper: "The Relation of the Architecture of an Interior to its Illumination."

May 18—Subject and speaker to be announced later.

June 15—"Modern Reflectors and Shades for Gas and Electric Lighting."

NEW ENGLAND SECTION

April 13, 1916. Engineers' Club, 2 Commonwealth Avenue, Boston, Mass. Paper: "Illumination of the Present and Developments to be Expected in the Near Future" by Dr. Charles P. Steinmetz, President of the Illuminating Engineering Society.

NEW YORK SECTION

April 6, 1916. Engineering Societies Building, 29 West 39th St., New York, N. Y. Paper: "General Problems of Illuminating Design" by Dr. Charles P. Steinmetz. Attendance 310.

May 11—"Symposium on Fixtures and Lighting Glassware" by Mr. Steven De Kosenko and several other speakers.

June 8—Outdoor meeting. "Electric Street Lighting in New York" by W. T. Dempsey.

PHILADELPHIA SECTION

April 21, 1916. Engineers' Club, 1317 Spruce St., Philadelphia. Paper: "Type C Lamps in Street Lighting" by T. J. Pace.

May 19—"Educational Aspects of Illumination" by Prof. F. K. Richtmyer, chairman, Committee on Education, Illuminating Engineering Society.

June 16—"Artificial Lighting for a Hundred Years" by William J. Serrill, Engineer of Distribution, United Gas Improvement Company.

PITTSBURGH SECTION

April 21, 1916. Fort Pitt Hotel, Pittsburgh, Pa. Papers: "Department Store Lighting" by E. R. Roberts; "Residence Lighting," by W. L. Collins; "Factory Lighting" by M. C. Turpin; "Office Building Lighting" by S. G. Hibben.

New Associate Members.

At a meeting of the Council held March 17, 1916 the following applicants were elected associate members:

OSBORNE, L. A.
Vice-president, Westinghouse Electric & Manufacturing Co., East Pittsburgh, Pa.

PEARCE, CHAS. BRYDEN
Superintendent, Wm. Hall Electric Co., 116 W. 4th St., Dayton, Ohio.

ROBINSON, R. C.
Research Laboratory of General Electric Co., Schenectady, N. Y.

Transfers to Grade of Member.

The following associate members have been transferred to the grade of member:

GLASGOW, ARTHUR G.
Humphreys & Glasgow, 36 Victoria St., London, S. W., England.
(Dec. 31, 1915.)

OSBORNE, L. A.
Vice-president, Westinghouse Electric & Manufacturing Co., East Pittsburgh, Pa.
(March 17, 1916.)

TRANSACTIONS

OF THE

Illuminating Engineering Society

VOL. XI — JUNE 10, 1916 — No. 4

TESTS OF STREET ILLUMINATION.*

BY PRESTON S. MILLAR.

Synopsis: The author distinguishes between routine tests to prove fulfillment of contractual obligations in street lighting and special investigations of the effectiveness of street lighting. The latter form the subject of the paper. After pointing out that the artistic or pleasing effects of the illumination are not at present reduced to a basis of measurement, the author describes methods which have been developed for testing the revealing qualities of street illumination. These include observational tests employing both automobilists and pedestrians, and basing conclusions upon their ability to see in the street. An elaborate test procedure of this kind is described and some results obtained by such observational tests are presented.

During the past twenty years a number of proposed tests of street illumination have been put forward. The more prominent among these have been based upon some one of the following criteria: light intensity in a particular direction; mean light intensity in a particular plane; mean light intensity throughout a stated zone; total light flux; vertical illumination intensity; normal illumination intensity; illumination intensity on surface inclined at angle of 45°; horizontal illumination intensity.

Each of these has been found to possess some merit and in a general way the merit may be said to have varied in proportion as the measure is comprehensive. Light in a particular direction or zone has afforded a less reliable indication than has the total light produced by a lamp. All these measures have to be interpreted and their proper interpretation is vital to the success of any one of them.

The application of all measures of street illumination has been complicated in the past in that the intent has been to make them serve both as measures of illuminating effectiveness and as means of proving fulfillment of contractual obligations. A forward step which assists in avoiding some of the misunderstandings in which

* A paper presented at a meeting of the Philadelphia Section of the Illuminating Engineering Society, February 18, 1916.

this matter has been involved in the past was recommended by the 1913 Committee on Street Lighting of the National Electric Light Association. The following quotation is cited from the annual report of that committee:

" * * * the best means of studying street illumination and arriving at the relative illuminating values of two different installations is not necessarily the best method of specifying the street lighting service which the street lighting contractor undertakes to give and the municipality agrees to purchase. At this point there must be a fundamental division of consideration. We have here two separate and distinct problems: in the first, that of deciding among several different systems of lighting and arriving at the best arrangement of the system selected, the purpose of street lighting must be considered, the fundamental principles of street illumination must be studied, and an effort must be made to gauge the extent to which these are accomplished. Consideration must be given to such questions as height, spacing, power of lamps and globes or reflectors. The surroundings and character of the street must be considered, and it is important to know the illumination intensity, maximum, minimum and average, the uniformity, the amount of glare, the color of light, etc. In the second problem, that of providing a means of proving fulfillment of contractual obligations, it is necessary to consider only the simplest and most reliable means of determining if the contractor is giving the stipulated and specified service."

The suggestion which has just been cited that tests of street illumination be separated into (*a*) those designed to determine the effectiveness of the lighting and (*b*) those designed to prove fulfillment of contract, immediately clears the situation and promotes proper consideration of these and other proposed measures. For proving fulfillment of contractual obligations it is important to select the simplest and most reliable method of determining if the lamps and the contracting company are doing what the specifications require them to do. The means adopted may or may not provide an indication of the effectiveness of the street lighting. To measure effectiveness of street lighting is altogether a different problem. Determinations of the effectiveness of street lighting should properly precede the letting of the contract and should be applied with a view to the selection of the best equipment and the adoption of the best form of installation. Through such means the contract may be made to cover lighting of the desired effectiveness. Provisions for testing fulfillment of such contract are properly stated to constitute an entirely different problem having no connection with that just stated.

TESTS TO PROVE FULFILLMENT OF CONTRACTUAL OBLIGATIONS.

There are diverse views concerning the best means of securing conformity to specifications in street lighting. It is the writer's opinion that, where possible, the contract should specify and describe the lamps to be used, their equipment and the operating practise, and that the contracting company should be called upon to provide assurance that the lamps, their equipment and their operation are as specified. Before the contract is let, it is well that both parties to the contract shall agree upon the facts regarding the qualities of the lamps specified in the contract. Good operating practise has already found means to provide assurance to the municipality concerning the qualities of the lamps installed and operated under the contract, and this without recourse to photometric tests under operating conditions. Nevertheless photometric tests are sometimes required and these often involve very considerable difficulties. The one basis of test which has the endorsement of engineering societies and electric light associations is the measurement of the total flux of light and for this the integrating sphere photometer has been found to be the most suitable instrument. When photometric tests must be made to prove correct operation, it is the writer's opinion that the most generally satisfactory method is to determine the total light flux, either in the laboratory or in operation. In either case the integrating sphere is applicable. Fig. 1 shows a 40-inch (1.01 m.) sphere as used by the Electrical Testing Laboratories in the measurement in service of the total light flux produced by arc lamps.

This method of test, here applied in streets probably for the first time, was found to be very satisfactory. The feeding interval of the arc lamps in this case was from 7 to 15 minutes. The lamp was lowered into the sphere. Photometric values were obtained throughout one feeding interval and the sphere was moved to the next lamp for a repetition of the process. In this practise about two lamps were measured per hour, and the accuracy attained is probably higher than could be reached by any other photometric method with a like expenditure of time and effort.

There are, of course, installations in which the use of the sphere is impracticable, as in the case of lamps rigidly mounted on high poles. In such case it would probably be necessary to assemble some of the lamps on temporary supports at a convenient place and there subject them to the sphere test, or else to take them to a laboratory for the corresponding test. In any event the writer's experience leads him to believe that where photometric tests are required in connection with contractual performance, the measurement of the total light flux with the aid of the integrating sphere is the best method which thus far has been devised and the one which is thoroughly satisfactory.

Whether the sphere or another method be employed, it is important that enough representative lamps be tested to afford a reasonably good indication of performance. It should be remembered that street illuminants may vary from a representative condition by 10 or 20 per cent. in light production. This imposes a requirement for a test of a considerable number of lamps.

It is, however, not the purpose of this paper to enter at length into a discussion of tests for contractual purposes. It is intended rather to deal with investigations of the effectiveness of street illumination.

INVESTIGATIONS OF THE EFFECTIVENESS OF STREET ILLUMINATION.

The several proposed measures of street illumination listed in a previous paragraph have in common the intent of providing a means of measuring the effectiveness of street illumination. Intensity to the exclusion of other variables of illumination is the measure embodied in all these proposals and intensity of light incident upon the observed object rather than light incident upon the street appears to be the underlying thought of those responsible for some of the proposals. Some of the reasons why it appears necessary to consider other qualities are given in the following paragraphs:

Sweet[1] in 1910, in a series of laboratory experiments, studied the effect of glare upon vision, and applied his findings to the problem of street illumination. The writer shortly thereafter repeated some of Sweet's laboratory experiments with substan-

[1] An Analysis of Illumination Requirements in Street Lighting, *Journal of Franklin Institute*, 1910.

tially similar results, but upon further investigation made *in streets* rather than in the laboratory found that the deleterious effect of glare in street lighting was much less marked than Sweet's application of laboratory results indicated. In the course of this work in the streets the writer was brought to recognize the importance of the silhouette effect which previously had not been considered in the engineering of street illumination. He also learned that specular qualities of street pavements were responsible for the introduction of entirely new elements into the problem, which led to great disparity between incident light and street surface brightness. Specular pavements, like the silhouette effect had not previously entered into engineering calculations of the street lighting problem.

These three factors in combination, the silhouette effect, the influence of specular pavements, and glare, must receive so much weight that the intensity of light incident upon observed objects which was formerly the only factor to receive much consideration, can no longer be regarded as an adequate criterion of illuminating value. They create a new general problem to which much of the earlier literature of street lighting is inapplicable.

In a recent paper[2] the writer presented the principal variables of street illumination as follows:

Intensity of Light upon the Street.—There is no single measure of intensity which serves all purposes. The average horizontal intensity upon the street surface is most nearly satisfactory.

Brightness of Street Surface.—Adopting automobilist's viewpoint as to angle and direction.

Relation between Lamps and Street Surface.—Visual angle between the two, and extremes of contrast encountered.

Contrasts Produced on the Street Surface and on Objects on the Street.—This is largely a function of the direction of the light.

Portion of Total Field of View Illuminated.—This may be affected either by the number of lighted lamps within view or by the area of surface which is illuminated.

Appearance of Installation and of Street by Day and by Night.—Lamps, fixtures, light distribution, etc.

[2] The Effective Illumination of Streets, *Proceedings American Institute of Electrical Engineers*, 1915; TRANS. I. E. S., 1916; third of a series of papers of which the two preceding papers were "An Unrecognized Aspect of Street Illumination", TRANS. I. E. S., 1910, and 'Some Neglected Considerations Pertaining to Street Illumination", TRANS. I. E. S., 1910.

These variables of street illumination in the same paper were shown to be dependent upon certain installation factors as follows: power of lighting units; number of lighting units per mile; kind of accessories; kind of mount; location of lighting units; nature of pavement; nature of surroundings.

Accepting this classification of the problem as fairly correct, we may well inquire if it is possible for any measure of street illumination which has to do exclusively with intensity of light to furnish an adequate test of street lighting effectiveness. The answer is plainly negative, since in recent years we have come to appreciate that with a given intensity of light upon the street the effectiveness of the lighting may vary, depending upon the nature of the street surface, the extent of glare encountered, the brightness of surrounding objects; and that all of these variables are dependent upon such installation factors as have just been named. In the writer's opinion any or all of these intensity measures are useful as providing definite descriptions of certain qualities of the illumination, but none of them can provide a comprehensive and reliable test of the effectiveness of street illumination.

In view of this fact it has become necessary to supplement earlier ideas in regard to street illumination tests, and indeed earlier ideas of principles of street illumination, and to develop a new system of consideration of the problem.

In studying the problem from this new viewpoint, the start has been made properly from fundamentals, and the following line of reasoning has been set up as a basis of methods which have been applied in investigation of street lighting effectiveness.

PRINCIPLES OF STREET ILLUMINATION UNDERLYING TEST PROCEDURE.

For any given cost to the public, street illumination should possess highest possible effectiveness.

Effectiveness is measured by the extent to which the lighting system fulfills its functions.

The functions of street illumination are first to reveal and then to please.

When appropriations for street lighting are small they may be devoted more wisely to securing maximum revealing power even

at the expense of esthetics. When the appropriations are large, so much light is produced that visibility conditions are necessarily excellent and in considerable part esthetic requirements may dominate even at the expense of specific revealing power. Fig. 2 is a suggestive non-specific diagram indicating that as the municipal expenditures for street lighting vary from a minimum to a maximum per linear foot per annum, the importance and indeed the possibility of securing pleasing effects vary from small to large, while the importance of obtaining maximum revealing power per unit of light varies from that of the first order to an order so low that it becomes relatively unimportant.

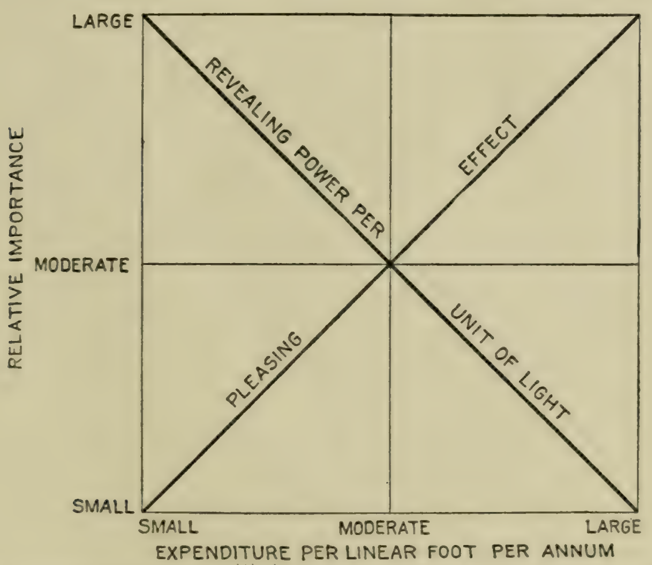


Fig. 2.—Illustrative diagram showing relation between street lighting expenditure and the importance of securing. (*a*) revealing power. (*b*) pleasing effect.

The application of every principle of street lighting and the relative importance of all variables in street lighting are affected by this changing condition growing out of variations in the amount of money devoted to street lighting. The chief desiderata in street lighting are usually considered to include: suitable intensity of illumination, reasonable approach to uniformity of illumination, reasonable freedom from glare. The extent to which any one of these should control the selection of an illumin-

ant and the design of a lighting system varies as the scale of expenditure increases, finally giving place as first desideratum to such factors as pleasing posts and fixtures. In consequence, no factor influencing the effectiveness of street illumination can be weighted as to its importance in comparison with other factors unless it is associated with the scale of street lighting expenditure. For example, statements as to the importance of a particular light distribution characteristic which may be correct for street lighting systems whose general scale is indicated by an expenditure of 25 cents per linear foot (30.48 cm.) per annum may be quite incorrect when applied to installations costing $1.00 per linear foot per annum. Any statement to the effect that a given equipment is the best for street lighting or that light radiated at a certain angle or in a certain zone is the most useful for street lighting, or that the promotion of silhouetting, or the elimination of glare is the most important thing in street lighting may be discounted at once; for, however, true the statement may be for a particular condition or installation, it cannot be true generally.

For this reason the subject of tests of street illumination is complicated and difficult. Obviously since there is no general requirement for all classes of street lighting, there can be no general measure of effectiveness and there can be no test which is generally applicable as a means of ascertaining street lighting effectiveness.

There would appear to be no gainsaying the basic proposition that the revealing and pleasing qualities of street illumination, weighted with regard to the class of street (roughly indicated by the expenditure for street lighting) determine the effectiveness, and that this effectiveness can be tested only by measuring these qualities. The relative pleasing qualities of two lighting systems are matters of judgement and taste which are not readily susceptible of definite determination. Possibly in cooperation with the psychologist further experience may develop methods of measuring the pleasing qualities of a street lighting system, but at present we have to rely upon expressions of preference. This important phase of evaluation of street lighting is not discussed in this paper, and the author begs leave to stipulate that its omission is not to be taken as indicating a low apprecia-

tion of its importance. On the other hand the relative revealing qualities of two lighting systems may be measured with approximate accuracy. It is therefore possible to determine the relative effectiveness of two systems of lighting for classes of streets in which the lighting expenditure is so low that the revealing quality of the installation is the principal and almost the only criterion, and for any class of street relative effectiveness of illumination may be determined insofar as this is a function of the revealing qualities of the lighting.

TESTS OF REVEALING QUALITIES OF STREET ILLUMINATION.

In devising a test of the revealing qualities of illumination it is logical first to determine what is to be revealed, and thus we come to the consideration of the objects of street lighting. These are to make the way safe by assisting in policing, and by rendering obstructions visible. When all principal requirements receive due attention it may be said inclusively that it is desired to reveal large objects on the street and irregularities in the street surface. These are the fundamental requirements of street lighting. If the relative effectiveness of two lighting systems in fulfilling these requirements can be measured, we shall have a measure of the value of the systems for revealing purposes. Unless street lighting systems can be so rated, we are without means of evaluating definitely street illumination. As a result of this consideration the writer in 1913 drafted certain proposals covering a prospective investigation of the revealing qualities of street illumination and sought an opportunity to carry out an investigation along the lines indicated in the proposals. In 1914, largely through the interest of Mr. John W. Lieb, then chairman of the Committee on Street Lighting of the National Electric Light Association, and through the courtesy of the Association of Edison Illuminating Companies, The New York Edison Company and manufacturers of electric lamps, it was found possible to undertake such investigations. The work was begun under the joint auspices of the Street Lighting Committees of the National Electric Light Association and the Association of Edison Illuminating Companies, assisted by an Advisory Committee consisting of a number of prominent members of the Illuminating En-

gineering Society. The street lighting systems were installed and operated by The New York Edison Company, the investigation was financed largely by the Association of Edison Illuminating Companies, and the tests were conducted by the Electrical Testing Laboratories under the writer's supervision. These investigations had to do principally with such matters as spacing interval, height and location of illuminants, and glassware equipment of illuminants. The general results of the investigation are embodied in the 1914 and 1915 reports of the Street Lighting Committees of the National Electric Light Association and the Association of Edison Illuminating Companies. Probably the most notable conclusions reached as a result of the work are that uniformity of illumination intensity is not necessarily desirable in street lighting; that, other things being equal, the illumination from a few large lamps is likely to be superior for street lighting to illumination from many small lamps and that a very considerable change may be made in intensity of light without influencing the effectiveness of the illumination so largely as does an improvement in the location or equipment of the lamps.

The methods of investigation as embodied in the original proposal covering this work were found in some particulars to be ineffective and unsuitable. Through the joint efforts of the Electrical Testing Laboratories and others interested in the work, these methods were developed in the course of the investigation until a high degree of effectiveness was attained, and when the investigation was brought to a close, it was felt that the scheme of investigation as a whole provided an excellent means of judging the relative revealing qualities of systems of street illumination.

In the summer of 1915 the Philadelphia Electric Company had occasion to make a determination of the relative effectiveness for street lighting of several types of lamps, and retained the Electrical Testing Laboratories to conduct such tests as might be required for this purpose. The tests which were applied were substantially those which had been developed in the investigation in New York City just described, and differed from the New York methods only insofar as local conditions made slight adapta-

tions necessary, and insofar as previous experience made possible the improvement of certain minor details. These tests therefore are substantially the same as the tests which were made under the auspices of the joint street lighting committee in New York City. The results, instead of those obtained in the New York investigation, are introduced in this paper, first for the reason that the latter have been published in large part, and second because the Philadelphia investigation possesses larger local interest. Through the courtesy of the Philadelphia Electric Company, who have kindly supplied the data and illustrations, the writer is privileged to describe this Philadelphia investigation and to set forth some of the results which were obtained.

DESCRIPTION OF TESTS OF REVEALING QUALITIES OF STREET ILLUMINANTS IN PHILADELPHIA.

For the purposes of such an investigation it is necessary to utilize a street which is level and straight for approximately 1 mile, and which is reasonably free from traffic at night. Such streets are rare, but one was finally located which served the purpose very well. This is Cottman Street in the northeastern section of the city between Bustleton Pike and Castor Road, illustrated in Fig. 3. The illuminants to be tested were installed on existing poles in positions approximating that secured by the standard pole bracket used in the outlying districts of Philadelphia. The light centers were approximately 22 ft. (6.70 m.) above the street level. The lamps of any two systems to be compared were placed alternately nearer to and farther away from the pole so as to secure comparable conditions. (See Fig. 3.) Poles are approximately 105 ft. (32.0 m.) apart and in most tests lamps were mounted on each alternate pole, though in some of the tests lamps on every fourth pole only were utilized. The lamps were operated on a standard 9.6 ampere direct current series street lighting circuit of the Philadelphia Electric Company with the exception of 4 ampere magnetite lamps which were run from a rectifier equipment. A temporary sub-station, Figs. 4 and 5, was used for the regulation of the lamps and for test headquarters.

Cottman Street is paved with an asphalt surface (Filbertine) in width only about 17 ft. (5.18 m.). This may be considered

to be equivalent to a longitudinal section of a wider street. If the lamps on such a hypothetical street are considered to be mounted over the curb, Cottman Street corresponds with a central longitudinal section lying between 8 and 25 ft. from the curb.

In most of the tests twelve lamps, spaced throughout approximately ½ mile at approximately 210 ft. (64.00 m.) intervals, were employed. The stretch of street between adjacent poles was alloted a number indicated on a placard on the pole (see Fig. 3.) Each such section was divided into five equal blocks the limits of which were marked by white stakes driven into the ground alongside the road (see Fig. 3). In addition the street was considered to be divided longitudinally into four lanes, lane No. 4 being nearest the lamps and lane No. 1 farthest from the lamps. The lamps employed were typical of the several kinds at the time the investigation was made. They were operated under the best practicable conditions, all precautions being duly taken to assure correctness of operation and to provide a record thereof. Globes were kept cleaned. The condition of the lamps and a description of the illumination characteristics was had through photometric measurements as follows:

Tests of total light flux made by lowering the lamps into a 40-inch integrating sphere mounted upon a truck (see Fig. 1).

Tests of horizontal illumination just over the surface of the street.

Tests of vertical illumination 4 ft. above the street surface.

In some cases measurements of brightness of street surface.

Tests of the revealing qualities of the illumination consisted in observations of test targets. These were of two kinds; observations by pedestrians upon small disk targets laid on the street surface and observations by automobilists upon larger vertical cylindrical targets located along the street. These tests will be described in some detail.

The disk targets were made of sheet iron, 2¾ in. (6.98 cm.) in diameter, painted and sanded to simulate the street surface. These approximated the street surface closely in color, but differed somewhat from the street surface in specular quality, being

Fig. 1.—Integrating sphere photometer in service in street tests.

Fig. 9.—Recording device and test automobile.

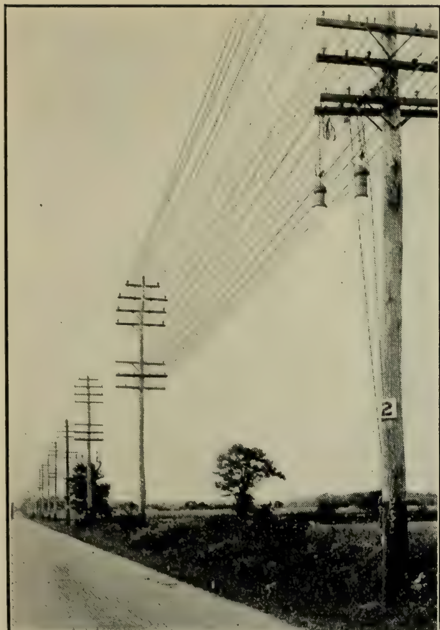
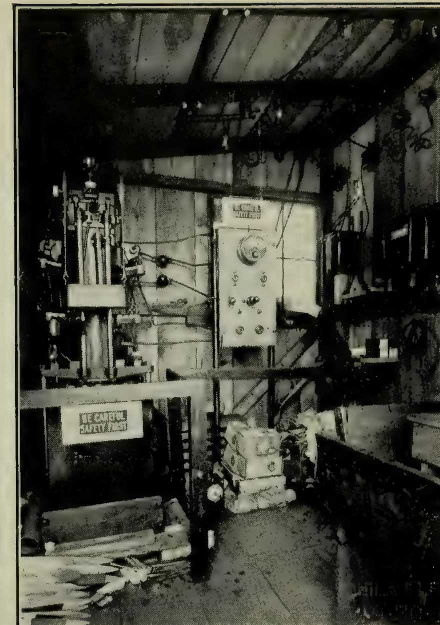


Fig. 3.—Cottman Street, Philadelphia, showing lamp mountings, street section designations and subsection markings.



Figs. 4 and 5.—Test-substation, exterior and interior.

Fig. 8.—Cylindrical targets—only four were used in any single observational test.

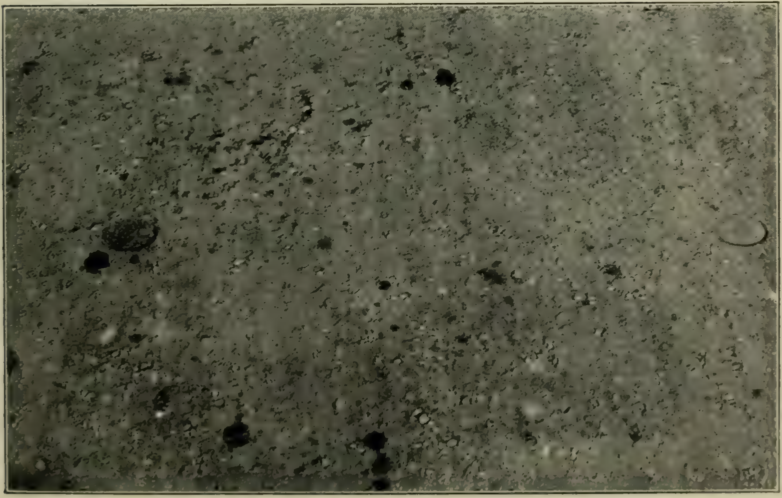


Fig. 6.—Disk targets on street surface.

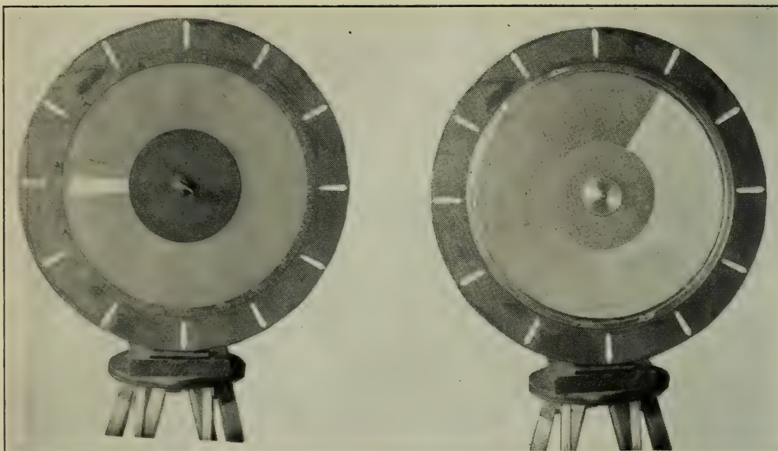


Fig. 12.—Variable contrast device for study of glare in street lighting showing cover disk in place and removed.

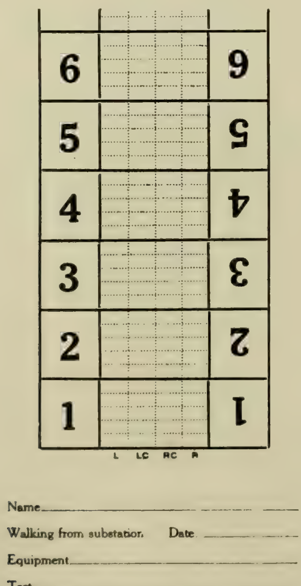


Fig. 7.—Portion of record chart for observations of disk targets.

in general somewhat less specular though the surface itself varied largely in this particular. Fig. 6 shows two of these targets laid on the street surface. Such targets were distributed throughout sections 3 to 18 of the street (a distance of about 1,680 ft. (512 m.)) in quantities ranging from 60 to 100. While the location of the targets appeared to be at random, it was in reality systematic and so designed that if instead of being distributed throughout 8 lamp intervals, all of the targets were assembled between adjacent lamps, but in corresponding locations with reference to the lamps, they would be found to be uniformly distributed over the street surface.

Observers, usually ten in number, walked through the street searching for these disk targets. The average speed of walking was about 3 miles per hour which including pauses for notes became 1.1 miles (1.77 km.) per hour. Whenever a target was seen, the observer recorded its location on a chart of which a portion is shown in Fig. 7. In general with average horizontal illumination intensities of the order of ¼ foot-candle, observers discovered approximately one half of the disks and failed to locate the remainder.

The time element in such observations is important, since it is evident that if an observer searched long enough he would find all of the disk targets which had been placed in the street. Therefore the time of search was recorded accurately and the results were reduced to targets found per minute in relation to the total targets "planted."

The general procedure was as follows: Boys trained in the duty planted say 70 targets at predetermined locations throughout the street. The first of two lighting systems to be compared was put into operation and allowed to burn for a sufficient time to secure normal operating conditions. Observers passed through the street one at a time searching for the disk targets and recording their findings. The second lighting system was then substituted for the first and the boys removed the disk targets and planted say 100 targets in other predetermined locations. The observers then retraced their steps, recording the location of disk targets found and returning to the starting point. The boys then removed the disk targets and replanted say 60 disk targets

in other predetermined locations. The observers again passed through the street recording the targets found. The boys then removed the targets and replanted 90 targets at other predetermined locations. The first system of lamps was then placed in operation and the observers retraced their steps, recording targets found and returning to the starting point. By this system trials 1 and 4 in combination provided a search for 160 disk targets distributed in a representative manner throughout the street, the first part of the test being accomplished by observers while they were least experienced and most free from fatigue, and the last part under the different condition that the observers were most experienced and most fatigued. Trials 2 and 3 combined afforded similar results for the other lighting system and occupied a midway position in point of growing experience and growing fatigue on the part of observers. On another occasion the same two systems would be compared by similar methods, but the system placed in operation second on the first night would be placed in operation first on the second night. By such means every effort was made to make the results comparable.

Table I is offered as a representative summary showing the result of one complete search for disk targets. It will be observed that 29 per cent. more targets were found under system B than under system A. Also that the targets found per minute of search are greater under system B than under system A by 28 per cent.

These two values are averaged in accordance with the system adopted by the Joint Street Lighting Committees for similar work in New York City. Four or five such tests are combined in order to provide a satisfactory comparison of two street lighting systems by this method.

In the other observational tests four cylindrical targets (see Fig. 8) 1 ft. high and 6 in. in diameter (30.48 x 15.24 cm.) were located somewhere throughout the length of the street, one target in each of the four lanes into which the street was considered to be divided. These, like the disk targets, were painted and sanded to simulate the street surface. Three observers rode through the street at approximately 18 miles per hour in order to ascertain the maximum distance at which these targets could be seen. After

TABLE I.—RESULTS OF SEARCH FOR DISK TARGETS SHOWING FINDINGS OF INDIVIDUAL OBSERVERS.

Observers	System A. Tests 1 and 4 combined.			System B. Tests 2 and 3 combined.		
	Per cent. targets found	Minutes consumed	Targets found per minute	Per cent. targets found	Minutes consumed	Targets found per minute
Collar	42.5	34.66	1.96	58.7	37.25	2.52
Clanton	40.0	31.08	2.06	56.3	33.00	2.72
Childs	39.4	45.83	1.37	48.75	33.33	2.34
Day	42.5	34.33	1.98	48.75	32.33	2.41
Gross	49.4	32.66	2.42	61.9	32.51	3.04
Hackett	43.1	31.01	2.22	53.75	30.66	2.80
Markley	47.5	32.58	2.33	66.9	36.75	2.91
MacArdle	45.0	32.41	2.22	55.6	32.75	2.72
Nixon	31.9	25.51	2.00	49.4	33.00	2.39
Quinlan	42.5	35.66	1.90	49.4	33.33	2.37
Averages	42.4	33.57	2.05	54.9	33.49	2.62

Ratio System B/A.

Targets found .... = 1.293

Found per minute .... = 1.278

Mean 1.29

they had passed the boys relocated the targets and the observers returned, again recording these maximum perception distances. The same precautions as described in the pedestrian tests were taken to assure comparative results, one system of lighting being employed first, the other system being substituted about one quarter way through the test and the first system being again put into service about three quarters way through the test. Twenty trips, or ten round trips were made by the observers in order to obtain comparative data on the two systems of lighting. These determinations of maximum perception distances were made on 40 target locations for each system of lighting, and these locations of course were distributed in a representative manner. In addition there were two repeated trips to test observers accuracy, yielding results which were comparable with two of the trips previously made. The targets employed are illustrated in Fig. 8, and the device for recording the observer's location when he first perceived a target is illustrated in Fig. 9. The observers sit on a sort of poop deck erected on the automobile. A strip of paper driven from the automobile hub passes under plunger keys, and its movement therefore is regulated by the movement of the automobile. A mark is made on the strip of paper to provide the basis of distance measurements, and it only remains for the observer to press the key indicating which of the four targets he has seen in order to secure a record of his location at the moment of perception. The record of the target planting shows its location and the distance at which it is first perceived may readily be deduced.

Occasionally a target is overlooked entirely. In that case the perception distance is recorded as zero and as such enters into the average. As any lighting which is not good enough to reveal these targets even at a short distance is poor lighting, such a record is penalized, the average perception distance being multiplied by the per cent. targets which are discovered.

Table II is a typical summary showing the results of one trial comparing two systems of lighting. The net result is an average maximum perception distance for the three observers of 682 ft. for System B and 616 ft. for System A. One target was missed Others were seen at distances ranging from zero (at the moment of passing) to 2,000 ft.

Observational tests of the character indicated are of necessity laborious and costly. Records show that under the best organized conditions one full night's testing yielded data as follows:

Walking Test: Findings of about ten observers in search for 160 disk targets each under each system compared, or a total of 3,200 determinations of which a typical result is 1,600 targets found, and 1,600 targets not found.

Riding Test: Observations by five observers (first, three observers, and second, one of the first three with two other observers), one man making two series, thus yielding six series of observations; 120 target locations for each system, 480 perception distances, of which a typical average value is 700 ft.

The organization for a typical night's work which produces results to the extent indicated above is as follows:

Representatives of the Electrical Testing Laboratories in charge of test	2
Philadelphia Electric Company officials	2
Statistical assistants	2
Observers participating in walking test	10
Observers participating in riding test	3
Boys handling the targets	4
Lineman	1
Chauffeurs	3
Passenger automobiles	2
Tower wagon	1
Test automobile	1
Truck	1

Some of the men participated in both the walking and the riding tests. A force for a typical night may be said to have aggregated 25 people. These had to devote their time to this work from 7:00 p. m. to a late hour ranging from midnight to 4:00 a. m.

Obviously such costly testing methods are not generally applicable. They may be employed only when extraordinarily important matters are involved. They have been adopted by the Joint Street Lighting Committees and by the Philadelphia Electric Company for the purpose of studying street lighting principles in cases where there have been no other means of obtaining the desired information.

TABLE II.—TYPICAL RIDING TEST SUMMARY.

Perception distances in feet for 40 target locations obtained in a riding test by three observers for each of two lighting systems. Data arranged to show systematic locations of targets through region between adjacent lamps.

	Lane No. 1				Lane No. 2				Lane No. 3				Lane No. 4.			
	Observer No.				Observer No.				Observer No.				Observer No.			
Trip No.	1	2	3	Trip No.	1	2	3	Trip No.	1	2	3	Trip No.	1	2	3	Average across street
System A.																
1	340	360	330	6	300	430	360	2	450	750	640	7	150	440	470	418
3	150	170	160	1	570	660	400	6	600	940	700	4	260	440	370	452
10	0	90	20	3	710	760	620	1	730	760	280	6	530	790	680	498
8	20	150	50	5	760	860	1130	4	720	990	1060	2	440	850	400	619
9	300	240	160	4	670	750	640	9	X	830	760	3	920	890	710	624
7	530	490	510	2	910	930	750	3	890	850	760	8	760	790	760	744
6	490	830	530	10	380	730	600	8	940	1100	1080	9	740	820	710	746
2	500	580	530	9	600	600	540	10	890	860	930	5	790	820	570	684
4	570	590	520	8	710	880	800	5	780	810	820	1	740	710	720	721
5	590	560	80	7	870	750	670	7	850	850	720	10	720	720	450	652
Avg.	349	406	289		648	735	651		761	874	775		605	727	584	616
System B.																
1	565	645	470	6	440	620	350	2	665	680	470	7	310	660	450	527
3	1180	510	500	1	505	650	430	6	140	600	110	4	160	130	750	472
10	110	90	10	3	770	780	710	1	780	1096	415	6	400	610	300	506
8	150	210	160	5	980	930	700	4	710	1060	470	2	620	790	470	604
9	580	460	290	4	870	1070	660	9	1230	1160	820	3	770	890	350	763
7	230	540	—	2	965	1045	770	3	1010	1120	850	8	980	1080	1050	803
6	840	660	590	10	960	920	760	8	1120	2000	830	9	890	870	830	939
2	825	665	615	9	740	710	640	10	980	1610	860	5	800	950	910	859
4	540	680	640	8	950	1110	730	5	860	1090	780	1	720	720	595	785
5	660	490	520	7	460	620	410	7	880	730	800	10	590	500	830	624
Avg.	568	495	380		764	846	616		838	1115	641		624	720	654	688

	Mean perception distance	Per cent. targets seen	Penalized perception distance
System A	616 ft.	100	616 ft.
System B	688	99.2	682

— Target was missed. X Target was not planted. Lane No. 4 nearest the lamp.

COMMENTS ON OBSERVATIONAL TESTS DESCRIBED ABOVE.

The tests which are here described are based upon observations at the perception threshold. In this respect they are similar to the better known visual acuity tests which are sometimes applied to interior lighting problems. They share the same qualities of low precision. Their application differs, however, from the application of threshold tests to interior illumination. In the case of interior lighting visual perception is not employed at threshold value. In street lighting it is often so employed. Hence a threshold test would appear to have more evident applicability in street lighting work than in the case of lighting of higher intensities.

It will be apparent that the results of observations will vary with the nature and size of the targets employed. Among the variables which had to be taken into account in the selection of targets were size, color, and contour. It is imperative that the targets be made difficult to see. If therefore they are very large or they present a considerable color or shade contrast to the street surface, all, or nearly all of the disk targets will be found and the larger targets used in the riding tests may be seen at greater distances than are available in the street, and at distances which are so great that they have little significance for street lighting purposes. When for one reason or another targets are so readily visible that all of them can be seen or that they can be seen at very great distances, considerable differences in the revealing quality of the illumination may be unnoticed. In proportion as the targets are rendered difficult to see, the test becomes sensitive and capable of discovering relatively small differences in the revealing qualities of two systems of lighting. In the course of the work at New York targets of various sizes, shapes and colors were employed, including for the riding tests, four 4-ft. (1.22 m.) gray targets, and smaller white targets and black targets, but the considerations just stated have led to the adoption of relatively small targets painted to simulate the street surface and therefore difficult to see under any kind of illumination.

It is the writer's judgment that in the necessity for making these targets difficult of observation the system has been ren-

dered slightly favorable to uniform lighting and slightly unfavorable to non-uniform lighting. For example, the disk targets being flat and presenting little or no vertical surface, the shadow which is of relatively greater importance in non-uniform lighting is reduced to a minimum; also in adopting a 1-ft. target, as compared, for example, with a four 4-ft. target for the riding tests, the advantages of silhouetting are reduced, to the detriment of the non-uniform lighting. However, if the method errs in this respect, it errs on the right side, because lighting to be good should be capable of meeting the most critical test, and that form of lighting which cannot meet the most critical test so well as another form should suffer accordingly.

Results in both the walking and riding tests may vary with the observer's qualities, the condition of the street surface and the condition of the atmosphere. The personal equation exercises a less serious influence upon the consistency of the results than do variations in the physical conditions affecting the observations. These latter are so marked at times as to make it imperative to regard the results only in a comparative sense. That is to say, the percentage of disk targets found under system A and system B by a given set of observers on a given night with the two systems employed alternately as described above, possesses a relative significance and is an indication of the relative revealing qualities for surface irregularities of the two systems compared. But the per cent. disk targets found under system A by a set of observers on one night and the per cent. found by another group of observers under the same lighting system on another night is not necessarily the same, and comparisons made between results found on different nights are usually not very significant. In passing, another point of difference from conventional visual acuity tests may be noted; namely, the biggest single variable entering into an investigation of this kind is change in condition of the street surface due to the presence or absence of moisture. In the usual forms of visual acuity test the observed object presents the same appearance at all times.

It is regarded as good practise to establish at least three comparative values for walking tests and six comparative values for riding tests on three nights, each based upon data of something

like the extent described above, before considering the relative illuminating values of two systems to be established within the limits of accuracy which this form of testing makes possible. Even then such a value is accepted only if the results for the three nights' work are reasonably consistent. If any unexplained inconsistencies are present, further work is deemed desirable before the final comparison is effected.

More consistent results would probably be obtained if trained and skilled observers were employed exclusively. It is not practicable to obtain the services of such men, and even if this could be accomplished, it is not certain that the employment of skilled observers would be found to be desirable.

SOME RESULTS OF TESTS.

From among the data made available by these testing methods one comparison is selected for presentation in this connection. This sets forth the observational results obtained when the street was lighted respectively by pony[5] broad carbon direct current open arc lamps of 9.6 amperes and magnetite lamps of 4 amperes, equipped with high efficiency electrodes.

Tables III and IV are summaries of the nightly observational results. Table III records mean findings of disk targets by several groups of pedestrian observers on several nights which range in per cent. targets found from a minimum of about 42 to a maximum of about 59 per cent. The mean deviation of nightly results from the final assigned value is 5.1 per cent. Table IV records variation in perception distances of observers who rode through the street locating cylindrical targets, ranging from a minimum of 420 ft. (128 m.) to a maximum of 815 ft. (248 m.). The mean deviation of nightly results from the average value assigned is 4.4 per cent.

The assigned observational values taken from Tables III and IV are included in the summary in Table V, which sets forth also the total light produced by the lamps and the illumination intensity along the street.

[5] Known colloquially as the "pony broad carbon lamp." When most lighting companies abandoned the pencil open carbon direct current arc lamp in favor of the enclosed carbon arc lamp, principally during the decade beginning with 1895, the Philadelphia Electric Company developed the broad carbon arc lamp, retaining the higher efficiency of the open carbon arc lamp and reducing operating costs by this method instead of by adopting the lower efficiency enclosed carbon arc lamp.

TABLE III.—SEARCH FOR DISK TARGETS—WALKING TEST.

Date	Number of observers	Targets found: Open carbon arc (Per cent.)	Targets found: Magnetite arc (Per cent.)	Targets found per minute of search: Open carbon arc	Targets found per minute of search: Magnetite arc	Relative findings, Ratio open carbon arc to magnetite: Found	Relative findings: Found per minute	Relative findings: Ratio assigned
9- 3-15	10	51.87	50.57	2.52	2.58	1.028	0.977	1.002
9- 7-15	10	44.62	41.70	1.66	1.84	1.070	0.901	0.986
9- 8-15	10	59.14	56.23	2.46	2.10	1.051	1.171	1.111
9- 9-15	10	45.75	51.85	2.27	2.34	0.882	0.969	0.926
9-10-15	11	46.30	42.15	1.89	1.92	1.100	0.984	1.042
Average—Final assignment of comparative value								1.013

TABLE IV.—PERCEPTION DISTANCES—CYLINDRICAL TARGETS—RIDING TEST.

Date	Test number	Open carbon arc: Average perception distance (Feet)	Open carbon arc: Per cent. seen	Open carbon arc: Penalized perception distance (Feet)	Magnetite arc: Average perception distance (Feet)	Magnetite arc: Per cent. seen	Magnetite arc: Penalized perception distance (Feet)	Relative penalized perception distance Ratio open carbon arc to magnetite arc	
9- 7-15	1	426	98.5	420	423	100.0	423	0.992	0.992
9- 8-15	1	727	99.2	721	706	100.0	706	1.020	1.029
	2	657	100.0	657	634	100.0	634	1.037	
9- 9-15	1	580	100.0	580	610	100.0	610	0.950	0.924
	2	738	99.2	732	815	100.0	815	0.897	
9-10-15	1	701	100.0	701	700	99.4	696	1.009	0.970
	2	691	100.0	691	743	100.0	743	0.930	
Average—Final assignment of comparative value				643			661	0.976	

TABLE V.

	Open arc lamps	Magnetite arc lamps
Total lumens per lamp—bare lamps	—	—
—equipped	5290	4649
Average foot-candles—horizontal	0.35	0.24
—vertical	0.29	0.20
Observational test relative results		
Disk targets, pedestrians	100	98.7
Cylindrical targets, drivers	100	102.4

This little summary is a condensed statement derived from a mass of statistical data which contains much interesting material. Some of the indications which are strikingly presented in these data are shown in Fig. 10. In the upper part of the figure are the familiar curves of illumination intensity throughout one lamp spacing interval. On the entire diagram the continuous line represents the open carbon arc lamp data and the broken line represents magnetite arc lamp data. It will be observed that the curves of horizontal illumination exhibit the usual peaks in the neighborhood of the open carbon arc lamp due to the very strong radiation at about the angle of 50° to the vertical. Midway between lamps the intensities are of the same order for the two lamps. The result is a more non-uniform distribution of intensity along the street when the open carbon arc lamps are employed. The lower left hand curves show the findings by pedestrians searching for disk targets under the illumination provided by the two types of lamps. The entire investigation has been laid out in such a way as to provide data extensive enough for the establishment of final average relative values for any two systems compared, but it is not sufficiently exhaustive to afford a precise determination of the relative values of the lighting for any one point along the street. Hence the precise course of these observational curves is not to be considered as definitely established. Their general trend properly indicates the lighting effect, but repeated determinations would probably result in considerable differences in the observational results for particular points along the street. One is struck immediately with the fact that these findings do not follow the curves of incident light as shown above. Midway between lamps where the illumination is relatively feeble, the disk targets are found about as well as they are in the regions nearer the lamps where the

illumination intensity is high. Here is definite evidence of the fact that intensity alone falls far short of providing

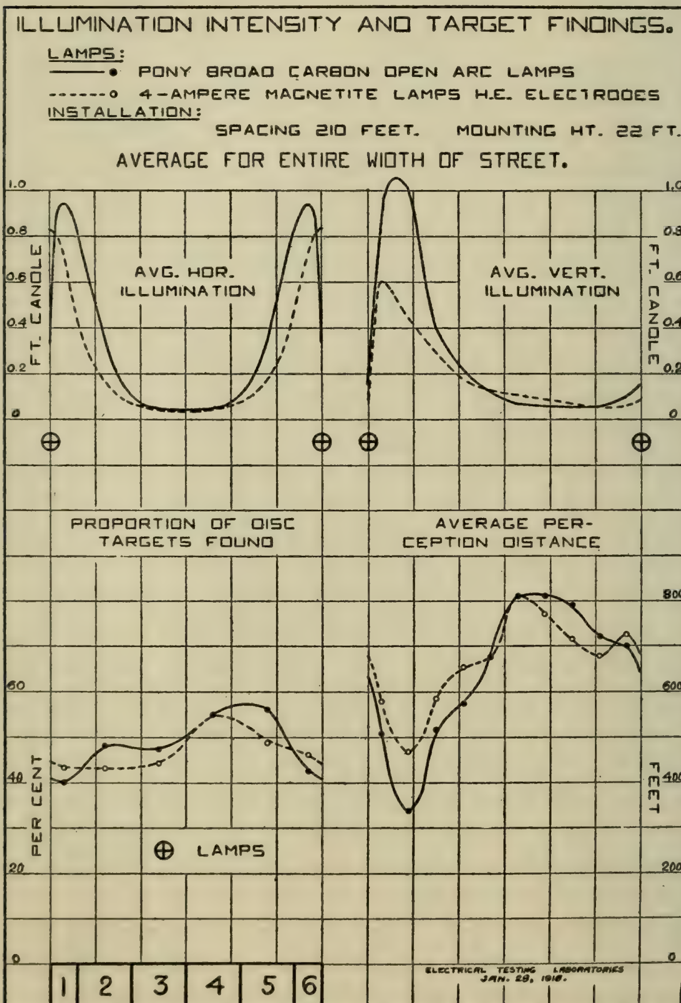


Fig. 10.—Illumination and observational data. The letters H. E. in the above title indicate that high efficiency and not standard electrodes were used.

an index to the effectiveness of the illumination. The disk targets are found in the brilliantly lighted regions near the

lamps because the intensities are high enough to reveal details under any probable circumstances. In the regions midway between lamps the intensities are relatively feeble, but the inclination of incident rays is such as to accentuate by shadows irregularities in the street surface; to make apparent differences in inclination of portions of the surface; and to make apparent differences in specular qualities of portions of the surface which might not be revealed when the disks are near the lamps. These several factors in combination probably account for the relative excellence of findings in the darker regions of the street. At first thought these findings appear unreasonable, but the explanation, as we have seen, is readily apparent and the results are undoubtedly as indicated.

On the right of Fig. 10 curves are shown of vertical illumination intensity and of maximum perception distances obtained in searching for cylindrical targets, while driving through the street. Here again the observational results exhibit radical departures from the curves of intensity of light incident upon the objects observed. Indeed it may almost be said that the targets are seen at a distance which varies inversely as the light which falls upon them. This is of course explained by the operation of the silhouette effect. When the targets are located in the brightly lighted area just beyond a lamp, they are seen to good advantage by means of the light which falls upon them. As the targets are located farther and farther beyond a lamp they receive less and less light, their surface becomes darker and more readily perceived as a silhouette against the brightly lighted background provided by the next lamp. The light from the open carbon arc lamp being distributed less uniformly than that from the magnetite lamp, there is a greater range of observational distance, shorter perception distances being obtained as well as longer ones. The silhouette effect is more pronounced because of the more brilliantly lighted areas provided by the open carbon arc lamp.

The extent to which the silhouette effect enters into visibility, depends of course upon the color of the object observed. If this object were black, the silhouette effect would be more pro-

nounced and the curve of perception distances would depart more radically from the character of the illumination curve than does the perception distance curve for the gray target as shown. If the object were white, there would of course be no silhouette and the curve of perception distances would probably conform more nearly to the character of the vertical illumination curve than is here indicated.

Some indication of the degree of precision attained in the riding test observations is derived from the repeated determinations of maximum perception distances which were made by

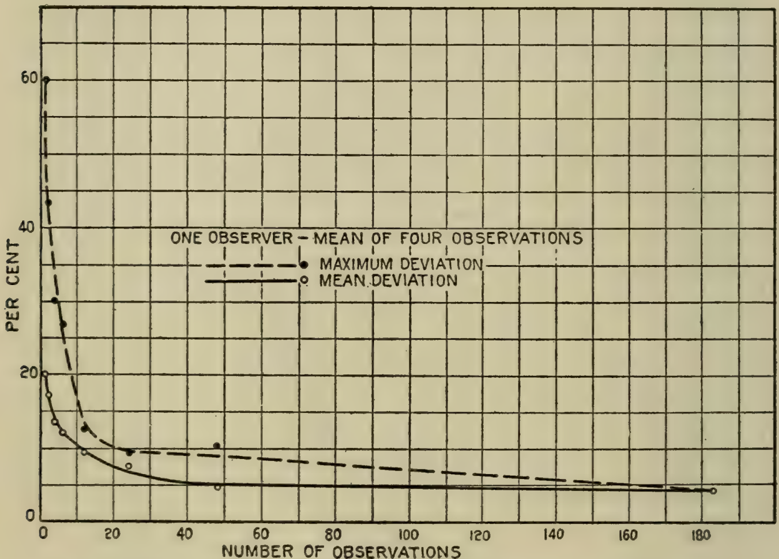


Fig. 11.—Degree of concordance found in repeated settings. The mean of four determinations by one observer is the unit upon which these curves are based.

three observers in the course of two repeated trips through the street as a part of each test. Statistics are so arranged as to yield readily the mean perception distance of each observer upon four cylindrical targets which were planted for a given observation trip and as a matter of convenience these perception data are therefore based upon such averages of four perception distances made by one observer during one trip. The results of this analysis appear in Fig. 11 and indicate that a repeated determination of four observational distances by one observer is

likely to vary from the first determination by about 20 per cent. and that the average of one hundred such repeated determinations of four values deviates from the mean value established by the first observations by slightly less than 5 per cent.; that is to say, if one observer makes one hundred trips through the street and repeats the observations under as nearly the same conditions as have been encountered in repeated observations made about one hour later, the average assigned value for the latter observational distances will be within 5 per cent. of that assigned as a result of the first trial.

This curve of observational precision is based upon the results as found. The variables which enter into these results include not only the personal equation, but as well changes in the atmosphere and corresponding changes in the street surface which have occurred in the course of an interval of something like one hour. If the physical conditions could be regulated to constancy probably these repeated observations would be in somewhat better accord with the original observations than as shown in the diagram. Also it should be noted that as a rule the repeated observations were made as a check upon the first observations made during the course of the test and that, therefore, the variables, whether those affecting the perceptive ability of the observers or those affecting the physical conditions, were likely to be at a maximum. Therefore, the probable precision of the work is somewhat better than that shown in the diagram, since the data upon which the diagram is based may be expected to reveal the largest deviations which would be encountered in repeating any of the observations.

The upper curve indicates the maximum conditions which have been encountered in repeated observations of the kind described. It shows that in one case the repeated determinations by one observer upon one hundred groups of four targets each resulted in deviations from the original assignments of as much at 7½ per cent. When only ten groups of four targets each are subjected to repeated tests by one observer it has been found that the maximum deviations encountered are 17 per cent.

The light produced by the respective illuminants or the light thrown upon the street as shown in Table V is of course the

stimulus which gives rise to vision. The statements of results in visibility tests are measures of the sensation produced by such stimulus. There is little information which may be looked to to establish the relation between the stimulus of light and the sensation of sight under street lighting conditions, but in general the sense reaction is small compared with the change in stimulus.

CONCLUSIONS.

This paper has described or referred to some usual and some unusual forms of test and has presented some results which have been obtained by such tests. The observational tests described are elementary in concept, though their application is complicated by many difficulties. They are the result of a desire to study principles of street illumination in order to learn the facts which have perhaps become obscured through the great variety of notions which prevail regarding street lighting requirements. The observational tests have been of great value to those who have participated in them, and not the least reason for this is that they have forced such persons to study street illumination in the street instead of in the office which has formerly been the prevalent method. Some of the facts which have been developed through these studies are of great importance and have promoted sound consideration of the street lighting problem, and not the least important conclusion strongly indicated by this work is that the total flux of light produced by a street illuminant which is reasonably well adapted to street lighting is likely to be a pretty fair index of its illuminating value for street lighting purposes; that while characteristic of distribution and other factors are important, yet any basis of rating which leads to the conclusion that the order of value of street illuminants is radically different from the total light produced should be accepted with caution and the burden of proof should rest upon those who advocate such a method of rating.

APPENDIX.

In the course of the work described herein two unusual kinds of tests have been applied; the first a test of glare and the second a psychological test to ascertain the effect of different lighting systems upon the attention.

In the tests of glare a contrast device was developed which

proved very satisfactory insofar as it was applicable, and which is believed to be the best available instrument for such work.[1] This is pictured in Fig. 12. Under the cover disk there is a photographically graduated paper which is revolved and which offers through a slit in the cover disk varying degrees of contrast. Starting with little or no contrast, the graduated paper is revolved until a condition of just perceptible contrast is reached. Comparison of such condition with and without a glaring source is expected to yield a measure of that part of the effect of glare which manifests itself in reduction in visibility. The slit in the cover disk may be located anywhere on the dial, and as the observer will not know its location until he is able to perceive it, his ability to tell the time indicated on the clock face offers a safeguard against the dangers of visualization which are so common in such work.

Tests of glare by this device, and indeed by all other devices which have been used, so far as the writer is informed are of little value for street illumination purposes, since they deal only with light incident upon the observed surface. It may easily occur that such a test may show a serious glare effect in reduction of visibility under conditions in which for street lighting purposes the glare effect is quite negligible due to enhanced visibility by silhouette. This inapplicability to street lighting purposes led to the abandonment of such glare investigations.

Psychological tests were made under the immediate direction of Dr. Harold E. Burtt, then an assistant to Prof. Hugo Münsterberg of Harvard University under whose general supervision the psychological tests were undertaken. These included tests of ability of the subjects to reproduce figures observed for a brief period and were intended to constitute a measure of attention and apprehension; tests of the ability of subjects to decide quickly and act accordingly, *i. e.,* tests of choice reaction and tests of motor co-ordination, involving subjects' speed and accuracy in performing a manual task. Dr. Burtt's conclusion as the result of his work is as follows:

> The main thesis that seems to be established by this investigation is that under a distinctly non-uniform illumination the attention of an individual walking through the street during a period of 20 to 30 minutes

[1] Described in *Electrical World*, Oct 20, 1910.

is at a higher level and his reaction time is quicker than when he is walking in a distinctly uniform illumination during a similar period. * * * The essential point for safety is the determination of whether a given stimulus is indicative of danger and the carrying out of the proper reaction, and the above experiments show that this process of deciding and reacting quickly is facilitated under non-uniform lighting. * * * The conclusion seems therefore warranted that, other things being equal, non-uniform illumination (of the type described) is more conducive than uniform illumination (of the type described) to the safety of the pedestrian.

The difficulty with such tests as those described in this Appendix and with other tests of single elements in the street lighting problem, is that however well the tests may be conducted and however accurate may be the conclusions which are drawn from them, yet it is almost impossible to determine what weight to attribute to them when they are applied as parts of the whole problem.

The observational tests which have been described in the main part of the paper commend themselves especially because of their all-inclusive character with respect to factors affecting the revealing qualities of the illumination. If glare is present to a harmful degree it will affect the observations and the results will suffer accordingly. If a particular distribution of the light stimulates mental alertness, this will be reflected in the observational tests. Hence it has been concluded that each factor which promotes or decreases the effectiveness of the lighting as far as visibility conditions are concerned, finds proper weight in the scale of influences brought to bear upon the observers in this form of testing.

The writer is under obligation to Mr. H. M. Poust for assistance in preparing this paper.

DISCUSSION.

MR. C. O. BOND: With regard to the chart with which the two things sought are revealing power, and pleasing effect, one may gain the impression that this pleasing effect is sought to be produced simultaneously with the revealing power; and yet the chief end of the pleasing effect is to make the installation presentable during daylight hours. All fixtures and posts are in the nature of necessary evils. We are much more conscious of the

physical appearance of an installation in the daytime than at night, for when the lamps are lighted they and their sustaining posts are likely to be thrown into obscurity.

On the ninth page occurs this sentence: "These are to make the way safe by assisting in policing, and by rendering obstructions visible." There is one thought which, by means of a sketch (Fig. A), perhaps I can make clear. In Philadelphia there are a number of streets which are one-way streets, that is, the traffic travels one way only. For instance, on Walnut Street the direction of travel is west, while on Chestnut Street it is east. The question occurred to me when speaking of the quality of safety in lighting, Where is it that most of our accidents happen at night on the streets? Collisions, I should think, happen mostly at street

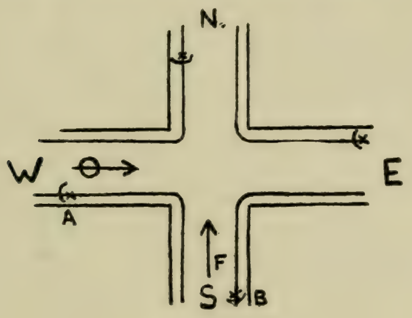


Fig. A.

intersections. Such accidents occur from lack of warning of approach. It is true that automobiles have horns, but another noise may at the moment drown a horn's alarm; or sounding it may be forgotten. Or it may be that horse-drawn vehicles are approaching. The present system of lighting piles up unnecessary illumination and creates glare at these very intersections. For this reason all shadows tend to be cast away from such intersections instead of towards them. Yet what better warning could there be than to use the ancient method and let "coming events cast their shadows before." A light with a reflector placed at *A* would cast *O's* shadow ahead to street *N S;* and a lamp placed at *B* would cast *F's* shadow ahead to street *W E.* Each would be warned of the other's approach.

I wish that while these tests were underway a trial had been

given of lamps with reflectors placed not over four feet above the street, all the rays to be distributed below the horizontal and in such way as to lessen highly lighted spots near the posts. One of the methods shown on the model to-night approached this, and was to me very pleasing. But the units were placed much higher than four feet, and this means that some glare would be met by the eye near the unit.

Some persons fear that under the 4-ft. system a man would seem to be walking in light up to his neck. But at least the street surface would be visible and he would not be facing brilliant sources the visible length of the street as now. That eye comfort and efficient seeing accrue under our present street lighting systems by shielding the lamps is easily proven by using a visor on a cap to exclude all direct rays from above the horizontal. The desire should be to remove as far as possible all light sources from the field of vision; that is the condition under sunlight and moonlight; and we shall never equal these illuminations partly because of the uni-directional shadows possible with them. But if our problem is to illuminate street surfaces, as nature does it, and not the houses, whose occupants neither pay for nor desire it, then the method suggested is at least entitled to a trial. It is unlikely that such units would be maliciously injured any more than are the present shop windows with their valuable displays.

On the tenth page, at the end of the first paragraph, it is stated "Other things being equal, the illumination from a few large lamps is likely to be superior for street lighting to illumination from many small lamps, and that a very considerable change may be made in intensity of light without influencing the effectiveness of the illumination so largely as does an improvement in the location or equipment of the lamps." In the conclusions on the thirty-second page it is stated that the best test after all is that of total flux, and that we cannot depart very far from it. But in the final table, on the twenty-seventh page, the magnetite lamp is 12 per cent. less than the open arc lamp, and the illumination from it on the horizontal is 30 per cent less, and on the vertical it is 31 per cent. less. And yet, to all intents and purposes, they are accepted as equal for the purpose of illuminating the streets. It seems to me that that discrepancy requires explanation.

In each search for targets, those of one character only are used, and the mind and eye fix their effort on that single quest. This is not a condition which would be found in practise where a variety of shapes were used. If the eye met the unexpected in this way, would the percentage of "found" be changed? I can understand that such a condition would be difficult to take care of in a test. I wonder whether any experiments have been made to cover it.

Mr. G. H. Stickney: A harbor pilot, on being asked if he knew where all the rocks were, is said to have answered: "No, I do not; but I know where the channel is." Now some of us have been acting as pilots in attempting to guide the planning of street lighting installations in safe channels, as indicated by contemporary practise. Mr. Millar, in this and preceding papers, goes somewhat further and reports tests undertaken to shorten or improve the channels, so as to establish better, safer and more economical practise.

There is something very deceiving about street lighting problems. Amateurs are continually suggesting changes in practise which are either impracticable or actually bad. In fact, experienced engineers have made some surprising mistakes in their attempts to better the practise. So that those who have studied illumination a long period of time are inclined to look at new suggestions with some suspicion until they have been tried out.

One of the great values of Mr. Millar's work is that it is well considered and tried out; therefore, any conclusions drawn can be relied upon.

There are a few minor points on which I would like to touch, in my endeavor to interpret some of the data. For example, in comparing the values given for Systems A and B (see Lane 3, Table II), it will be noted that at some points the values obtained for System B are lower than any for System A. The average, however, is brought up by high rating at other points. This would seem to indicate that there are some points at which the seeing value of the illumination in System B is poorer than anywhere with System A, in spite of the fact that the average value for System B is higher than that for System A. This raises the question of whether or not average values obtained from such

data are a true measure of the relative lighting values. It would seem logical to give some weight to uniformity, though I am not prepared to say how much.

It is interesting to note at the right of Fig. 10 that the minimum visibility corresponds very nearly with that of maximum illumination. This suggests the much discussed question of the relative value of uniform and non-uniform street lighting. In most of the discussion that I have heard, these have been treated as representing only two conditions. In reality, we practically never have uniform intensity of illumination, but a very large number of degrees of non-uniformity. Undoubtedly for a given set of conditions there is some one degree of uniformity, which may be a little better than any other, but I believe this is a variable for different conditions, and as far as I know the law of its variation is not very well understood. Of course, we generally assume that with high intensity lighting the illumination should be more uniform than with low intensity lighting. The demands of different uses of the street may affect the degree of uniformity which would be most effective.

Mr. Millar's test being made for a definite object takes into consideration only certain conditions and, of course, cannot be interpreted literally for other conditions, although it is very valuable in being a basis for approximation.

In view of the amount of study and effort being given toward determining the best practise in street lighting, it is unfortunate that sometimes (not so often now as formerly) the expert's recommendation is set aside by those having political influence. The appearance of the lighting in a street may be marred by the demands of a city official that a lamp be placed in front of his house, or that it be removed from in front of his house, according to his personal taste.

Mr. Bond mentioned a scheme of lighting the street surface from very low sources, arranged so as not to emit light above the horizontal. Something of this order is used in some of the parkways in Baltimore to reveal curb lines. The general idea I have heard discussed a number of times, and know of some experiments being carried on with it. I doubt if it would be satisfactory in a street lined with buildings, especially if appearance were of any consideration. It is my experience that in such

a street, if the light is cut off from the buildings, the effect is very disagreeable. I saw this illustrated in a western city several years ago, when the 1,000-watt lamp first came out. Although there was a high intensity on the pavement, the street appeared dingy and unattractive, whether viewed from near the lamps or from the distance at which the lamps themselves were not visible. I cannot think of any built-up city street in which such lighting would be acceptable.

PROF. C. E. CLEWELL: This paper illustrates a practical application of the engineering method of attacking a complex problem. In a commercial test on an electric generator or motor there may be a constant quantity and one independent and one dependent variable; in other words, the factors entering into the test are usually few in number and easy to handle. The author has mentioned some twenty-five or thirty variables entering into his tests on street lighting. The successful solution of a problem of this kind undoubtedly requires a very high grade of engineering.

Several items stand out with particular prominence. Among these is the emphasis on the practical use of the integrating sphere photometer for total flux of light measurements on street lamps in service. Another is the reference to Sweet's laboratory experimental studies on the effect of glare upon vision as applied to street illumination. The author certainly presents some new and interesting viewpoints on the glare problem, and his demonstrations of the advantages of glare in certain cases from street surfaces, and the silhouette effect from unprotected distant lamps, have been most instructive.

It is significant that these tests were based on fundamentals and that those in charge of the test approached their work with minds open to conviction rather than with a hypothesis which they were attempting to prove. The functions of street illumination which the author sets forth, namely, first to reveal, and then to please, although simple statements, are representative of the factors which go to make up the problem. The curves of illumination intensity and target findings are of considerable practical interest, and they show the almost paradoxical fact that many objects are seen best when farthest removed from the lamp.

It is discouraging to find that the testing methods described in this paper are too costly to make them generally applicable, and it is to be hoped that some simplified scheme for securing these general results in other cases may be devised, thus making these tests available to other localities.

Mr. Thomas Sproule: It was my good fortune to have had considerable to do with the tests which Mr. Millar described this evening, and I enthusiastically subscribe my endorsement to the methods used in obtaining the results which have been shown on the screen. I am of the opinion that it is impossible for anyone who has not been actively engaged in a test of this nature to appreciate the thoroughness with which such a test is conducted. It is only natural to draw the conclusion that the results will vary considerably with the personal elements. Such is not the case, however, as a thorough study of the results obtained night after night indicates very consistent results. Personally, when this test was started, I had very preconceived ideas as to what street lighting should be, feeling that first consideration should be given to a uniform light distribution on the street surface. My opinion has been very much changed, which change has been a gradual one, and is the result of the many observations, under test conditions, which I personally have made during the Cottman street test. It is most unfortunate that a test of this kind requires so much time and such a large expenditure of money.

We are particularly fortunate in that Mr. Millar has been able to present these results to you personally, and I regret that time does not permit a more detailed analysis, as I am sure the results of such an analysis would be most interesting to everyone present.

Mr. J. R. Cravath (Communicated): The results given in Mr. Millar's paper are very interesting and valuable, as is also his clear analysis of the general subject. The following remarks are intended as amplification rather than adverse criticism. In reviewing the work of the 1914 street lighting committees Mr. Millar states that probably the most notable conclusions reached as a result of the work are that uniformity of illumination intensity is not necessarily desirable in street lighting; that other things being equal the illumination from a few large lamps is likely to be superior for street lighting to illumination from many small lamps and that a very considerable change may be made

in the intensity of light without influencing the effectiveness of the illumination so largely as does an improvement in the location or equipment of the lamps. It occurs to me that there is some danger that a statement like this which appears on its face to be rather broad may be given a broader interpretation than intended by its author. The 1914 committee's tests referred to were all made with a comparatively short distance between lamps as on business streets. But in residence lighting generally, throughout the country, with the exception of some of the larger cities, the distances between lamps are so great that shortening of the distances between lamps is sure to result in improvement as there is no danger of getting light on one spot from too many lamps. It would be unfortunate if the conclusions stated by Mr. Millar were quoted to defend some of the unquestionably bad residence street lighting conditions which we have throughout the country. There is undoubtedly a limit beyond which it is not advisable to go in the direction of securing uniformity, but all the New York tests referred to were well within that limit. When the illumination midway between lamps becomes so low as compared with that near the lamps that discernment is extremely difficult, the conclusions from the New York tests of the committee do not apply.

While I agree with Mr. Millar's conclusions that the total flux of light produced by a street illuminant is likely to be a pretty fair index of its illuminating value for street lighting purposes, the necessity for applying this principle with caution is evident from the results of Mr. Millar's Philadelphia test as summarized in Table V. In this table although there is a decided advantage shown by the open arc lamp in total lumens, horizontal foot-candles, and vertical foot-candles, the observational tests results show the two lamps to be practically on a par. This indicates to my mind quite clearly that the extremely non-uniform distribution of intensity along the street surface with the open arc lamp entitles it to a considerably lower rating per lumen of output. The disadvantage of the large amount of flux thrown on the street near the lamp by the open arc is further emphasized by the low perception distance curve, Fig. 10, for the point near the lamp.

While it is true that tests of glare by the device described and

other devices such as those used by Sweet do not take into account the conditions of illumination on any portion of the street, I do not think we should discard these glare tests as of no value on that account. It is desirable that the effect of glare be measured independently of all other conditions as far as possible, so that the exact amount of the glare effect independent of other conditions may be given proper value. Then after the glare effect has been determined the other variable factors can be brought into the problem.

Mr. P. S. Millar (In reply): My statement of street lighting principles has been prepared from the test point of view. Mr. Bond's discussion has to do with proposed designs of street lighting systems which is a rather different subject. It would be very interesting to see an exemplification of Mr. Bond's ideas in practise. I should anticipate, however, that his proposal to light the street by concealed sources mounted under hoods 4 feet above the street level would be mentally unsatisfying. One likes to see the light source, especially if it is pleasing in appearance; also when the buildings along a street are of interest, it adds much to the lighting effect if they are moderately illuminated instead of being left in darkness as would be the case with the system which Mr. Bond proposes. Consider Broad Street as an example. Under Mr. Bond's system it would be a strip of illuminated asphalt and would look much like any other street of the same width. As lighted at present, it is Broad Street, Philadelphia, one of the notable avenues of the country.

Mr. Bond says that it is stated in the paper that "the best test after all is that of total flux and we cannot depart from it." A reading of the paper under the caption "Conclusions" will make it clear that the statement was qualified and is in purport not quite in accord with the citation. To explain why the less powerful lamp, the magnetite lamp, produces an illumination which according to these observational tests is the equivalent of that from the more powerful lamp, the carbon arc lamp, would require a more detailed analysis of the illumination than has been made in this paper. I believe that the findings are fully explained by the differences in light distribution characteristic and by the fact that 12 per cent. change in the amount of light produced in the street cannot be expected to influence ability to see appre-

ciably; that is to say, a 12 per cent. change in the stimulus produces but little change in the sensation.

Mr. Stickney's suggestion that weight ought be given to uniformity of lighting effectiveness appeals to me strongly. He made the same suggestion in connection with our New York work and we sought a method of applying it to our test results. In this we did not succeed. We did, however, conclude that none of our conclusions was seriously affected by neglect of this fact. For example, we tried eliminating from our records all perception distances greater than 1,000 feet and found that it did not alter our conclusions. We tried penalizing very low perception distances and found that none of our conclusions was altered. As shown in the paper, we have penalized every condition which was so bad that a cylindrical target was overlooked altogether. This was at least in the direction of meeting Mr. Stickney's suggestion.

I am glad that Mr. Cravath has submitted his qualifying remarks on the indications of the paper. With one of his comments, however, I cannot agree. The minimum perception distance shown in Fig. 10 is not due in any way to "the large amount of flux thrown on the street near the lamp." If all the excess light near the open carbon arc lamp were eliminated, substantially the same low perception would probably be encountered. Perception distances here are small because substantially the same amount of light falls upon the target as upon the street beyond it which forms its background. Hence there is lack of contrast.

As to the applicability of glare tests which have been made I can only say that so far as I know these have never been weighted in comparison with other effects involved and hence the difficulty in thus weighting them limits their applicability severely and they therefore become largely of academic interest. The observational tests which are described in this paper give glare its proper weight among the other variables.

GLARE IN STREET LIGHTING.*

Synopsis: The distinctive features of glare in street lighting are due (1) to the condition of the eye itself, and (2) to the character of the lighting. The sensibility of the retina, and therefore the brightness sensation, depends upon the average brightness and average contrast of the field of view, the size and brightness of the brighter parts of the field and finally upon the rate of change from light to dark in passing along the street or in sweeping the field with the eyes. These factors in visual sensation are related to the brightness, intensity and position of the lighting units. The laws governing glare and vision are outlined and the causes of glare in street lighting discussed.

I.—INTRODUCTION.

In the lighting of streets, lighting conditions are such that excessive contrasts cannot be entirely avoided. There is no difficulty in providing an average illumination well above the minimum required for comfortable vision, but to provide this without introducing glare has not been found practicable. The problem of obtaining the best seeing conditions at a reasonable expense therefore requires very careful analysis and a fairly precise knowledge of the reactions of the human retina to light. In the end these data must be translated into data on the size, brightness and position of lighting units with due consideration to the character of the street and the nature of the traffic.

This committee has defined *glare* to be such a distribution of brightness within the field of view as to cause discomfort, annoyance or interference with vision. The discomfort or annoyance can only be estimated or roughly measured by a nervous fatigue test. Interference with vision is measured as a depression of visual acuity or of contrast sensibility and threshold sensibility. In ordinary street lighting, conditions governing visual discomfort do not run parallel with those causing interference with vision.

The *classes of glare* with which street lighting is concerned are as follows. Brightness glare is glare due to an excessive general brightness of the field of view. Temporary brightness glare is that due to a sudden increase in the brightness of the field of view far in excess of that to which the retina is adapted. Intermittent glare and flicker are due to large irregular or periodic variations in brightness. Contrast glare is glare due to excessive

* Report No. 13, I. E. S., Committee on Glare, (1914-15.)

contrasts within the field of view. Spot glare is contrast glare in which the brighter area subtends but a small angle. Contrast or spot glare is either central or oblique. Quantitative definitions and recognized limits of tolerance of these forms of glare may be found in the general report[1] of the committee.

RETINAL REACTIVITY TO LIGHT AND CONTRAST.

Normal Vision.—Vision out of doors is at its best when the greater part (60 to 80 per cent.) of the illumination is from nearly overhead and nearly parallel light and the remainder well diffused, that is, when no contrasts exceeding 20 : 1 are within the field of view. Such conditions obtain under a high sun or full moon with a moderately clear sky. The eye readily adapts itself to very wide ranges in the absolute brightness of the field of view. Comfortable, acute vision is possible with a field brightness ranging from 0.05 millilambert up to 10 lamberts. From 0.01 ml. to the threshold of vision (about 0.00001 ml.), the power to distinguish details falls off steadily. Below 0.005 ml. hardly anything more than outlines are perceptible even to the accommodated eye.

Below are given data on the normal operation of an average eye; first in the steady state, viewing fields not containing excessive contrast, then on the depression of sensibility due to varying brightness and finally the depression due to spot glare, both axial and oblique.

The performance of a normal average eye under different illuminations and contrast have been sufficiently determined for engineering purposes and are outlined in the table below. Data are given for the four levels of average brightness of most interest in illumination. The complete curves may be found elsewhere in the TRANSACTIONS.

NORMAL PERFORMANCE OF AN AVERAGE EYE.

	I Mean brightness level	II Relative contrast perception	III Instantaneous threshold	IV Relative threshold sensibility	V Relative contrast sensibility	VI Relative glare sensibility
1	1,000 ml.	1.00	0.35 ml.	1	1	1
2	10 "	0.57	0.017 "	20	60	200
3	0.1 "	0.14	0.0014 "	350	1400	18000
4	0.001 "	0.021	0.00011 "	3100	22000	160000

[1] Report No. 1, I. E. S., Committee on Glare, TRANSACTIONS I. E. S., vol. X, p. 987.

1. Approximately the average brightness of objects out of doors in full daylight, very dull days excepted.

2. The average brightness of the field of view in interiors with natural daylight illumination.

3. The average brightness in interiors under artificial illumination.

4. A rough average brightness out of doors at night. On some well lighted streets the brightness is above 0.1 ml.

II. The relative contrast perception is the relative just noticeable difference measured as a fraction of the brightness at which it is measured. The actual fractional differences just perceptible are 0.017, 0.030, 0.123, and 0.79. This may be represented by the function $P = Pm + (1 - Pm)\ (I/I_0)^{-n}$ when $Pm = 0.017$, $n = 0.45$ and I_0 is the threshold.

III. The instantaneous thresholds are the brightnesses just perceptible (without waiting for adaptation) to an eye fully adapted to the brightness given in I.

IV. Relative values of III. This is a measure of the ability to see anything at all at the different brightness levels. The complete curve (threshold brightness) is represented by $T = Tm + (1 - Tm)\ (B/B_0)^{-n}$ when $Tm = 0.00022$, $B_0 = 0.000017$ ml. and $n = 0.49$. Hence, at the rather low levels of brightness associated with street lighting, where B_0/B is dominant in the formula, sensibility (measured by $1/T$) is roughly equal to the square root of B, or, in other words, the sensibility is proportional to the square root of the brightness.

V. Relative contrast sensibility is proportional to the difference in brightness (in, say, ml.) that is just perceptible with the eye adapted at the various levels. It is a measure of the ability to distinguish faint contrasts.

VI. Relative glare sensibility is inversely proportional to the brightnesses that will give the same sensation of glare. For example, if a given street lighting unit produce at night a given glare, it would have to be about 160,000 times as bright to produce the same glare sensation at noonday, because the eye is so much less sensitive in full daylight.

Since visual sensibility depends upon the flux density of light at the retina and this is proportional to the brightness of the field

viewed, visual performance is properly expressed in terms of brightness rather than illumination.

Vision with Varying Brightness.—In passing along an unevenly lighted street or in successively viewing objects of different brightnesses, the eye changes its level of adaptation. Visual sensibility changes from any given level of adaptation to any other, at a given fixed rate determinable in the laboratory. In the following table are given data on the rate of change of sensibility of an eye adapted to darkness then suddenly exposed to a brightness of 25 ml. and the reverse. Twenty-five millilamberts is quite blinding to an eye adapted to darkness, but yet only a thousandth as bright as the average automobile headlight and not nearly as bright (¼ to 1/50) as an average large street lighting unit.

Ratio of Change of Sensibility

0 to 25 ml. and 25 to 0 ml.

Time	0 to 25 ml.	25 ml. to 0
1 second	2.1 times decrease	1.6 times increase
2 seconds	4.2 " "	2.6 " "
5 "	16.2 " "	7.6 " "
10 "	58. " "	14.4 " "
10 minutes	120. " "	21. " "

For example, if suddenly exposed to such a brightness, the eye in five seconds drops to one sixteenth its sensibility and after five seconds subsequent exposure to darkness has by no means recovered its sensitive state. On a lighted street, the sensibility adapts itself to the brighter places more rapidly than it recovers in the darker, the net result being that the retina is less sensitive than it would be if exposed steadily to the average brightness. Street lighting is (other things being equal) much more efficient when more evenly distributed. It would be much less efficient than it is were there not such a lag of sensibility behind sensation.

The adaptation rate for various degrees of contrast from 1 : 0 to 10 : 9 are given in the following table for an initial adaptation to 0.1 ml., a brightness a little above that of a well lighted street. The values in the table are the brightnesses necessary to make the contrast at the head of the column just visible after the time in the first column.

CONTRAST ADAPTATION, 0.1 ml.

Time	Contrast just visible			
	1 : 0	10 : 1	2 : 1	10 : 9
Instantaneous	.0010	.0013	.0044	.021
5 seconds	.00013	.00014	.00053	.0053
10 "	.000053	.00010	.00042	.0042
30 "	.0000021	.000028	.00018	.0030

With a contrast barely perceptible (about 100 : 97) the sensibility does not increase at all after the first few seconds. Under the conditions of ordinary street lighting and traffic, therefore, every increase of contrast and every second of time is of great moment in rendering detail perceptible.

Depression of Sensibility by Spot Glare.—The depression of visual sensibility caused by spot glare depends upon three distinct factors: (1) the angular *size* of the glare spot, (2) its *brightness,* both absolute and relative to the surrounding field, and (3) its angular *position* with respect to the axis of vision. All three are of vital importance in practical street lighting.

In the following table are given data on the effect of different sizes and brightnesses of glare spot. A field of a given brightness was varied in size from a full field down to a pin head at each brightness level.

EFFECT OF SIZE AND BRIGHTNESS OF SPOT ON SENSIBILITY.

Solid angle of bright spot	Field 1.0 ml.	17 ml.	170 ml.	600 ml.
Full	0.0064	0.074	0.29	1.2 ml.
1.0	0.0050	0.074	0.27	1.4
0.1	0.0065	0.074	0.26	1.5
0.01	0.0090	0.074	0.22	1.5
0.001	0.0125	0.074	0.13	0.84
0.0001	0.0161	0.074	0.08	0.15

These data show that if the spot is not very bright, a decrease in its size (at constant brightness) is attended by a considerable depression in sensibility while, on the contrary, if it be quite bright the reverse is true. At an intermediate brightness, sensibility is nearly independent of the angular size of the glare spot. With a fixed size of spot, the absolute sensibility of the retina decreases considerably with increasing brightness of spot.

These data relate to infinite contrast; that is a bright light against a dead black background. For lesser contrasts the effects

are similar but less pronounced until finally with barely perceptible contrasts the effect of size of field disappears.

The effect of a central black spot in a bright field is of less practical interest but it may be mentioned that in every case such a dark spot enhances sensibility.

The (logarithmic) depression of foveal sensibility caused by a glare spot decreases uniformly with the angle with the axis of vision. Data on relative threshold are given below for a field brightness of 0.1 ml. and a frosted lamp of about 1 lambert in brightness.

Angle	0°	10°	20°	30°	40°
Relative threshold	0.11	0.17	0.26	0.42	.65

Beyond 50 degrees no depression was perceptible. The angle from the axis of vision in street lighting is expressible in turns of mounting height and separation of units.

SUMMARY OF GLARE DATA.

Seeing conditions depend only slightly upon the mean brightness level (if this lies between 0.1 and 1.0 ml.) but vary enormously with spot glare.

Spot glare greatly increases the mean brightness required for a given visual sensibility, hence from the standpoint of visual efficiency is extremely wasteful of light.

Spot glare near the axis of vision depresses sensibility (1) in proportion to the solid angle which it subtends at constant brightness, and (2) in proportion to the square root of its brightness at constant angular size. Hence, a diffusing globe on a lighting unit, while it may lessen discomfort, does not affect the depression of sensibility except insofar as it lowers total candlepower.

The depression of sensibility due to spot glare is a linear function of the angle away from the axis, vanishing at about 45 degrees.

STREET LIGHTING PRACTISE.

To be complete, this report should contain a section on street lighting practise. This involves consideration not only of (1) the fundamental *principles* of street lighting outlined above, but of (2) the *expense* of construction and maintenance and of (3) the *appearance* of the lighting units and their surroundings.

In the present state of the art, however, the committee finds that on account of the diverse requirements of street lighting and of the variety and complexity of the considerations involved, no concrete statements can be made which are generally acceptable to experts in street lighting practise. No report entirely free from controversial matter can be made until principles, cost and appearance shall have reached a satisfactory compromise through extended practical trial.

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J. R. CRAVATH,
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P. G. NUTTING, *Chairman.*

INCANDESCENT LAMP DEVELOPMENTS.*

G. S. MERRILL.

Synopsis: The initial characteristics and life-performance of gas-filled incandescent lamps are affected by several details of design not encountered in the case of lamps with evacuated bulbs, so that it is quite essential, in evaluating such lamps, to use a somewhat more comprehensive standard of comparison than has heretofore ordinarily been required. That the mean horizontal candlepower (which served as a convenient rating for the vacuum lamps) is not a practical, adequate measure of the luminous output of gas-filled lamps has been rather generally understood. That the initial efficiency of the newer lamps may be not at all indicative of the average economy with which they operate during life possibly has not been as generally recognized. Gas-filled lamps can be made in certain sizes, the average efficiency of which will not be more than from 3 to 5 per cent. poorer than the initial figure, while variations in design may produce lamps which will show an average efficiency from 10 to 15 per cent. poorer than the initial value. Thus two such lamps showing the same initial luminous efficiency may differ by as much as 10 per cent. in average efficiency throughout life. Some factors which affect the ratio of average efficiency and initial efficiency are discussed, and the importance of giving careful consideration to the average performance both in the design and in the application of the lamps are emphasized.

The incandescent lamp has been in a continuous state of development from the time the first filament was made to glow by an electric current and for years research work of the most highly specialized nature has been carried on in the effort to produce better and better incandescent illuminants. Every line of investigation that appeared to have any bearing on the problem has been followed out with such painstaking care that it may be said in consequence that a special branch of chemical and physical science has been developed. As a direct result of this research the lighting industry has been enriched by many marked advances in the art of lamp making which have carried the incandescent lamp through the several distinct stages with which we are all familiar, and have served to place the tungsten filament lamp in such a prominent position in the lighting industry to-day that no consideration need be given to the classes of incandescent lamps it has now so effectively superseded. As the tungsten filament lamps were gradually perfected

* A paper read at a meeting of the Chicago Section of the Illuminating Engineering Society, March 16, 1916.

and improved for ordinary lighting service, they also found new and extended applications, and one field after another has been completely thrown open to them.

Certain of these fields of service such as street lighting, train lighting, automobile lighting, flashlight and small portable battery service have become very important; others involving more specialized applications hold forth great promise of future development and the manner in which recent improvements have served to extend the sphere of usefulness of the Mazda lamp has already been the subject of many papers and discussions before this and other societies. However, the lamps used for ordinary multiple lighting service represent such a large part of the value of lamp sales that they must be regarded not only as the "bread and butter" part of the lamp business, but as the most important application of the incandescent lamp in lighting service. The improvements in such lamps due to recent developments are of more direct consequence to the great majority of incandescent lamp users than the creation of new fields of service and the importance of an increase of even a few per cent. in the economy of light production affecting this class of service can hardly be over estimated.

The most striking improvement in recent years, which has greatly increased the efficiency of light production attainable in commercial service with the incandescent lamp, has resulted from the use of inert gases in the bulbs of tungsten filament lamps. This new form of construction, which has produced the line of Mazda C lamps, introduced a number of new factors in the problem of lamp design, and these will be discussed with particular reference to their effect on the performance of the lamps for multiple lighting service. A few of the more important special applications directly dependent upon the new form of construction will then be mentioned to emphasize some of the characteristics of the Mazda C lamps. In order to appreciate the general nature of the problems that have been encountered in working out a form of construction for the gas-filled lamps which will, all things considered, give the best possible service in the great field of ordinary multiple lighting and to see how the development work has been directed to accomplish certain desired ends, one must first have a clear idea of how the introduction of

a gas into the bulb of an incandescent lamp affects its design and operation.

To start with imagine a lamp having a tungsten wire filament in the form of a single V-shaped loop supported in a bulb from which all the air has been exhausted. If a steady electric current is made to flow through this filament it is heated to such a temperature that the rate at which it loses heat energy just balances the rate at which it consumes electrical energy. Now in such a vacuum lamp this energy is dissipated from the filament in two ways: first, a relatively small part, possibly 5 per cent., is conducted away from the filament by the wires which support it, or which bring the current to it; second, by far the greater part is converted into radiant energy which appears in the form of radiant heat and light.

If more current is made to flow through the filament it consumes more energy and its temperature will rise until the rate of loss of energy again balances the rate of input. The amount of light produced by the filament increases much more rapidly than the watts consumed by the filament as its temperature is increased. For example with a tungsten filament in a vacuum at 2,100° C. each watt of electrical energy produces about 9½ lumens, at 2,300° C., the luminous output per watt is increased about 60 per cent. and at 2,500° each watt produces a little over 2¼ times as much light as at 2,100°. Obviously, as far as the efficiency with which electric energy is converted into light is concerned, the higher the temperature the better.

However, the production of light with incandescent lamps is a practical commercial process, and as such must take into account another very important factor, *i. e.*, the length of time the filament will last when operated at these different temperatures. For example, if a tungsten filament in a vacuum at 2,100° would operate 1,000 hours, at 2,300° it would operate about 40 hours, and at 2,500° but 2 or 3 hours.

In order to make a lamp capable of giving the ultimate consumer a maximum amount of light for a given expenditure of money, a certain adjustment between the cost of energy consumed and the cost of lamp renewals must be secured. The cost of energy required to produce a given quantity of light depends on the efficiency of the lamp and the unit cost of energy. The

lamp renewal cost depends on the life of the lamp and its price. Both the efficiency of the lamp (affecting the cost of energy consumed) and the life (affecting the cost of renewals) depend upon the temperature at which the filament is operated. The smaller lamps with tungsten filaments in a vacuum are operated at an initial temperature of about 2,100° C., at which temperature they produce about 9½ lumens per watt and have a rated life of about 1,000 hours.

The disintegration of the filament which limits its life at high temperatures is caused by the evaporation of the filament material to such an extent that some one spot becomes unduly thin, is greatly overheated and melts through, or until the filament is so weakened that it can no longer support itself. When the filament is operated at a high temperature the particles of material evaporated are projected from the surface with a high velocity, and if the filament is in a bulb from which all gases have been exhausted there is nothing to interfere with the progress of these particles until they strike the lamp bulb, where they are condensed. The condensation of filament material eventually becomes visible on the bulb as a very thin deposit, which is, in part, responsible for the blackening of the bulbs which have been used for a long time. The decrease in the life of a lamp caused by an increase in filament operating temperature results directly from the increased rate at which material is evaporated from the filament.

If any way could be devised by which the filament could be operated at a higher temperature without decreasing the life one would have a possible method of improving the economy of operation of the incandescent lamp. If, for example, some new filament material could be invented or discovered which, in addition to other necessary properties, had a very high melting point and would not evaporate or disintegrate rapidly at temperatures much below this melting point, it might be possible to obtain more light per watt without seriously decreasing the life of the lamp. This is exactly the line of development that lead through the carbon filaments, untreated, then treated and then metallized, then to the tantalum, and finally to the tungsten filament. The melting point of carbon is higher than that of tungsten but the disintegration of the carbon filament, which becomes appreciable

at a comparatively low temperature, places a very definite limit on the efficiency commercially attainable with lamps of this class. The tungsten filament, however, does not show as great a tendency to disintegrate rapidly at a temperature as far below the melting point, and can therefore be operated commercially at higher temperatures and with higher light producing efficiency. Another possible way by which higher operating temperatures may be attained has been made evident by Dr. Langmuir's[1] study of the causes of filament disintegration.

As a result of his research work it became evident that by operating a filament in a bulb filled with some gas that would not enter into chemical action with the filament, it would last much longer than if it had been operated at the same temperature in a vacuum. The increase in life due to the presence of the gas may be explained as follows. If the filament is surrounded by a gas instead of being in a vacuum, the particles of material evaporated apparently can not travel to the bulb nearly as freely as before because their paths are blocked by the molecules of the gas. It seems in fact that the particles evaporated from the filament collide with these gas molecules almost before they leave the surface and these collisions drive a great many of them back to the filament surface again thereby reducing the net rate of loss of material from the filament at the given temperature.

If this were the whole story it would be a fairly simple matter to improve the incandescent lamp by simply filling the bulb with an inert gas, but there is another feature which serves to make the problem much more complex. The gas which is put in the bulb to decrease the rate of evaporation and make higher operating temperatures possible also carries heat away from the filament and it is found that in order to maintain a filament at the same temperature in a gas as in a vacuum it must be supplied with a greater amount of electrical energy. Inasmuch as a given filament operating at a certain temperature will produce the same quantity of light regardless of whether it is in a gas or in a vacuum, a gas-filled lamp is less efficient at the same filament temperature, than a vacuum lamp of otherwise similar construction. However, as the introduction of the gas reduces the rate of filament evaporation the filament can be operated at a higher

[1] See papers on "Tungsten Lamps of High Efficiency," by Irving Langmuir and J. A. Orange, *Trans.*, A. I. E. E., 1913.

temperature to give the same life as before. This increase in operating temperature increases the light output per watt, and it will more than counter-balance the loss in efficiency due to loss of heat through the gas, provided that this loss is not too great in the first place. It is with the specific problem of reducing this heat loss through the gas that the development of the best lamp for commercial service has been very much concerned.

At a given filament temperature this heat loss will depend upon the effective area of filament surface exposed to the cooling action of the currents of gas and on the ability of the gas to carry energy away from this surface. Dr. Langmuir as a result of his extended investigation found that this heat loss was nearly

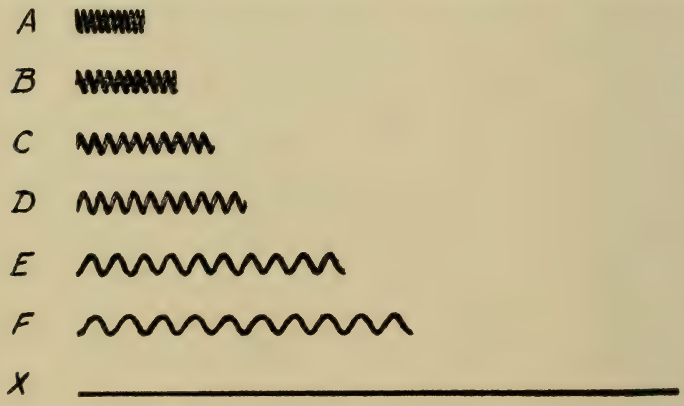


Fig. 1.—Illustrating filaments coiled experimentally to different coil spacing, each representing a length of wire as shown by x.

as great for a filament of small diameter as for one several times as large and also that by coiling a filament in the form of a rather closely wound spring the effective cooling surface exposed to the gas could be very greatly reduced. The ability of the gas to carry heat from the filament has been found to depend upon the nature of the gas, the pressure of gas in the bulb, the manner in which the gas currents circulate about the filament when it is heated and several other details of design.

As will be evident later, the practical success of the gas-filled lamps has depended upon the ability to coil the tungsten filament in a comparatively small space to reduce the effective cooling sur-

face and this has only become possible with the perfection of the ductile, drawn wire filament. These filaments can be wound with coils close together on a mandrel barely twice the diameter of the filament itself, an operation that would have appeared impossible of attainment in the early days of the tungsten filament lamp. The length of filament condensed into a coil such as might be used in a gas-filled lamp is shown in Fig. 1, *X* and *A*. Inasmuch as coiling is involved in the design of all gas-filled lamps it is interesting to note how the coiling affects the radiating properties of a filament before considering its effect in reducing the heat lost through the gas.

Since the radiation from a given filament at a given temperature would be the same in an inert gas as in a vacuum, in order not to complicate the present consideration of the radiating properties of a coiled filament compared with a straight one, let it be assumed that one is dealing with filaments in exhausted bulbs.

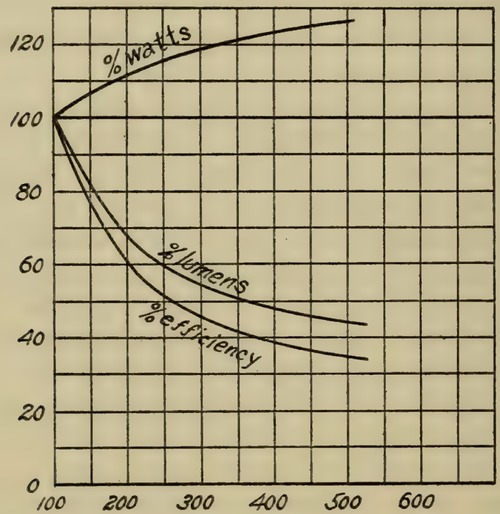
Let it be imagined that one can take the straight filament in an ordinary vacuum lamp and coil it about as shown in Fig. 1A. When the filament is wound in this manner, part of the energy radiated from each coil is intercepted and absorbed by the neighboring coils and the net rate of energy radiation is materially reduced, so that it may require only 60 or 70 per cent. as much electrical power to maintain it at the same temperature as before. However, part of the radiation cut off by adjacent turns is reflected and it so happens that tungsten will reflect relatively more of the heat radiation than of the radiation in the visible spectrum. In consequence of this selective reflection, the reduction in light output will be greater than the reduction in wattage and in the case of vacuum lamps at a given operating temperature the coiled filament will therefore be somewhat less efficient.[2]

Although the coiling of a filament changes its radiating properties, it serves to reduce the convection loss through gas in the case of the gas-filled lamps so very much that for the present pur-

[2] At the same efficiency, the life of a coil filament vacuum lamp will consequently be somewhat less than that of a vacuum lamp with the same filament uncoiled. This will in part explain the lower rated life of the vacuum lamps in which coiled filaments are used to give a relatively high candlepower in the direction of the tip. The Mazda B coil lamps are of this construction and are designed to operate at the same efficiency (spherical candles per watt) as the corresponding lamps with the ordinary straight filament; but, in order for them to do this, they must be operated at a higher temperature and their rated life will therefore be somewhat less than that of the ordinary straight filament lamps.

pose of illustrating the second point the first need not be considered separately.

Let it be supposed that there are several gas-filled lamps which are identical in every detail of construction, with the exception that the filaments represent several degrees of coil spacing as illustrated in Fig. 1, *A*, *B*, *C*, *D*, *E* and *F*, the wire from which these coils are made being such as would ordinarily be used in a 100-watt gas-filled lamp of 115 volts, the same length being used



Coil spacing per cent.

Fig. 2.—Showing how the wattage, luminous output, and efficiency of a gas-filled lamp can be changed by varying coil spacing, other details of construction being the same. Initial performance when tested at a given voltage.

in each case. The usual method of coiling is represented by the most closely coiled filament, designated as *A*, Fig. 1. The coiling represented by *B*, *C*, *D*, *E* and *F*, Fig. 1, is such as would be obtained by stretching coil *A* from its original length as indicated. If coil *A* represents 100 per cent. spacing, coil *F* (five times as long) would represent 500 per cent. spacing.

If the wattages and total lumens of these lamps were measured when they operated at 115 volts, the results would be about as shown graphically in Fig. 2. When operated at the same voltage, it is found that the filament temperatures are decidedly different. A vacuum lamp made up with an equivalent uncoiled filament

would give about 120 per cent. as much light and consume 95 per cent. as much energy at the same voltage as the gas-filled lamp with the most closely coiled filament and, although much more efficient, this high efficiency would be attained only by a great sacrifice in life. It will be seen from Fig. 2 that at a given voltage the amount of power consumed by the gas-filled lamps increases and the amount of light produced and efficiency decrease as the coils spacing increases. The rate of deterioration of the filament would also decrease as the coils are stretched out by reason of the lower operating temperature. If the temperatures of the filaments whose coil spacings are greater than normal were raised to bring the rate of deterioration up to that of the most closely coiled filament so that they would give the same life the amount of light they produce, their wattage and their efficiency would all be increased, but their efficiencies would not even then be as high as that of the lamp with the most closely coiled filament. The vacuum lamp, if operated to give the same life as the normal gas-filled lamp would produce about 80 per cent. as much light for the same wattage with this particular size of filament.

If the comparisons just made had been based on the use of a filament of larger diameter, such as might normally carry five, ten or twenty amperes instead of about one, the advantage of the gas-filled construction over the vacuum lamp would have been even more marked, for the heat lost through a gas in case of a heavy filament is relatively less than from a filament of small diameter and other things being equal higher efficiencies of light production can be attained. The data presented will, however, serve to show the importance of having the filament coiled as closely as possible to reduce the heat losses. The question of performance of these lamps throughout life and its relation to their design constitutes another very important phase of the problem we have just considered.

It is of course very desirable that any illuminant should maintain its luminous output well throughout its life, and should show a high *average* operating efficiency. The gradual evaporation of material from the filament of an incandescent lamp will decrease its light output and efficiency to some extent as the lamp becomes old, but it is quite necessary in the case of a gas-filled lamp to

avoid using a construction that will, in itself, cause the lamp to show an average efficiency or light output much lower than the initial value. Such undesirable characteristics usually result from constructions that permit the coil spacing to change as the lamps are burned in such a way that the temperature of the filament is decreased with a corresponding reduction in the light produced and the efficiency. The data given in Fig. 2 show how greatly these quantities are affected by changes in coil spacing when the experimental lamps are operated at a given voltage, as is the case in ordinary multiple service.

The typical performance of four lots of lamps each represent-

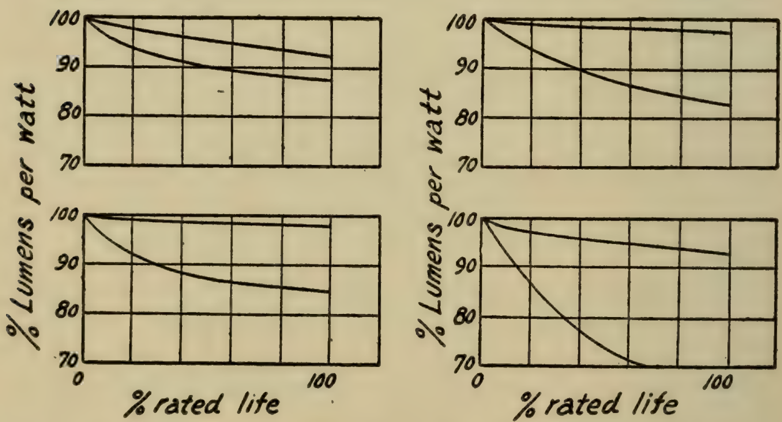


Fig. 3.—Typical performance showing efficiency throughout rated life of four lots of gas-filled lamps each lot representing two different forms of construction.

ing two radically different forms of construction is illustrated in Fig. 3 in which the efficiency of light production is shown for each construction throughout life. The necessity of considering the average performance rather than merely the initial rating in lamp design is well indicated by these curves and the fact that the average performance throughout life is of much more importance to the consumer than the initial showing should also be quite evident. The reduction in temperature due to changes in the filament form lowers the rate of filament depreciation and lengthens the life, but as soon as the filament departs from its original closely wound form the lamp becomes inherently poorer in quality and incapable of giving as satisfactory service under any condition

as a lamp which has been designed to maintain to a high degree its initial light output and efficiency. To see that increased life obtained from a lamp which shows a marked change in filament temperature from such a cause is not a real advantage we have only to compare the economy of light production attainable with such a lamp with that of a lamp which does not exhibit this characteristic.

Since the energy consumed by an incandescent lamp will ordinarily cost the ultimate consumer from five to ten times as much as the lamp itself the gain of even a few per cent. in the average efficiency of light production may be shown to be of very material importance by expressing it in terms of the cost of the lamp.

In ordinary multiple lighting a difference of 10 per cent. in the average value of lumens per watt produced by two lamps during life would make the less efficient lamp worth perhaps but 30 per cent. as much to the consumer as the lamp which showed the higher average operating economy providing that the two lamps had the same average total life. However, the less efficient lamp by reason of its lower average efficiency might be expected to show a somewhat greater total life than the other (even though its useful life might be less) and assuming that its total life might be even twice as much as that of the more efficient lamp, an analysis of the cost of producing light might still show it to be worth only about 60 per cent. as much. Not only would such a lamp be less economical in service, but it would show a greater reduction in light output during its period of service which is an additional disadvantage. The initial efficiency of such a lamp might be as high or even higher than that of the lamp which shows the better average performance and if judged by this alone its value would be over-estimated.

Before passing on to a comment on some of the special applications of the gas-filled lamp a few words about its rating and characteristics in general may not be out of place.

The photometry of the gas-filled lamps is not quite as easily accomplished as that of the vacuum lamps. In the first place the lamps cannot ordinarily be rotated in order to get a mean candlepower reading without setting up unusual currents in the gas surrounding the filament which change the normal filament temperature and light output. In the second place the relation between

the mean horizontal and the mean spherical candlepower is not as definitely fixed in the case of coiled filament lamps as in the case of the ordinary lamps; therefore the mean horizontal candlepower can be taken only as an approximate measure of the total light output. Moreover there have been so many different lamp constructions on the market that the total light output basis of rating is particularly needed. These considerations have lead to the use of some form of integrating photometer, such as the Ulbricht sphere with which the total light output of a stationary lamp can be measured by one reading. In using the integrating sphere for such work special attention must be given to the selective qualities of the interior surface and in general precautions must be taken to avoid error through color difference. The relative size of the sphere and light source, the character of the test plate, the best working range of intensity of the test plate illumination in relation to the rest of the photometric equipment all must be carefully considered.

Incidentally, it may be mentioned that all Mazda C lamps are rated on the basis of total light output, the efficiencies being given in terms of watts per spherical candlepower. The regular Mazda C lamps for series lighting service are now designed to give certain fixed total lumens. The candlepower rating of these lamps is retained but is considered only as a nominal value. The number of lumens for which the several sizes are designed is ten times the nominal candlepower in each case.

By reason of the high operating temperature of the filament in gas-filled lamps and the localized heating of the lamp parts by the current of hot gas that ascends from the filament, it has been found necessary to limit the use of certain of the larger lamps to the positions for which they have been designed. The smaller lamps can ordinarily be used in any position. However, even if a lamp is regularly furnished for burning in one position, it can usually be furnished for other positions of burning on special order. In order to meet these special requirements, however, it is necessary in some cases to modify the design in such way that the efficiency of operation is somewhat diminished. The manufacturers have recognized the desirability of having their product capable of burning in any position, but where it would be necessary to make a material sacrifice in efficiency in order to

meet the requirements of a very limited demand, it has seemed best to make the bulk of the output, intended for ordinary tip down burning, as efficient as possible and to treat the demand for other constructions as special cases. Lamps for certain special classes of service are designed to operate in the positions in which they are generally used, such as tip up for ordinary stereopticon and headlight service. The temperatures of these lamps and the wiring adjacent thereto have been investigated with much care in connection with their design and applications.

The gas-filled lamp, because its filament is concentrated into a relatively small space and may be operated at a high temperature lends itself especially well to service where a concentrated source of high brilliancy and candlepower or where a whiter light than is obtained with the vacuum lamp is desired. The highly concentrated source is particularly suited for projection work, one phase of which is represented in the flood lighting of exteriors. While this application of light is by no means new, it has been brought into prominence by reason of the ease with which striking yet dignified and beautiful lighting effects can be secured with the gas-filled lamps. In flood lighting highly concentrated beams are not ordinarily desired and for such service the coiled filament need not be condensed into a very small space, but in certain classes of projection and stereopticon work where the lamps are used with carefully designed optical systems to secure a maximum screen illumination or a maximum intensity and concentration of the beam of light, the filament must be condensed into the very smallest space possible and the candlepower per unit of effective area must be made very high. This concentration does not refer to the actual spacing of the turns in the winding but to the disposition of the coiled filament itself within a small space by the arrangement of the supports. For such projection and stereopticon service it is found economical to force the filament temperature far above the normal value which secures about 75 per cent. more light from a given filament area with a life of one or two hundred hours. The importance of high intrinsic brilliancy and concentration in lamps for such service cannot be too strongly emphasized, and in such service it is not always the case that a lamp of higher wattage will give better results. In fact a lamp of higher wattage with a filament necessarily less

highly concentrated (due to its greater size and length) may even give poorer results than a lamp of lower wattage. It is not possible to predict just how far the incandescent lamp can successfully progress into the great field of projection work, but the outlook is most promising.

The use of the gas-filled lamp for the production of whiter light or as a basis for the production of daylight in various degrees of approximation has been particularly favored by reason of the high filament operating temperature normally attained. The whiter quality of light has probably been an important factor (in addition to the higher economy) in extending the use of the gas-filled lamps in ordinary multiple service. But it is possible to go further in the direction of producing approximate daylight by the use of absorbing screens or specially designed bulbs, which with an absorption of about 35 per cent. give a quality of light that might be called "afternoon sunlight." With higher absorptions nearer approximations to noon sunlight, or to north sky daylight can be reached. The greater actinic value of the radiation from filaments at temperatures attainable with the gas-filled lamp have made it possible for these lamps to find successful application in photographic studio work and for certain classes of this service a special blue bulb lamp has been developed which has met with much favor.

The particular development which has been made the special subject of this discussion is not, by any means the only one that has contributed materially to the recent improvement of the incandescent lamp. In addition to this and other more striking developments there have been countless refinements in details of construction and manufacture that have improved the quality and uniformity of the product in general and have very materially decreased its price. Moreover all the efforts of the lamp manufacturers to improve lamp service do not involve the physical design or construction of the lamp. No little effort has been made to assist the ultimate consumer to use the lamps to the best advantage by impressing him with the importance of selecting them with particular reference to the circuit upon which they are to be used and in general by leading him to apply judiciously the fundamental principles of illuminating engineering in their application to his lighting problems.

TRANSACTIONS

OF THE

Illuminating Engineering Society

NO. 4, 1916

PART II

Miscellaneous Notes

Council Notes.

A meeting of the Council was held April 13, 1916, in the Electrical Laboratory, Massachusetts Institute of Technology, Boston, Mass. Those present were: C. O. Bond, H. Calvert, C. A. B. Halvorson, C. L. Law, M. Luckiesh, J. Arnold Norcross, Preston S. Millar. Upon invitation: Louis Bell, C. E. Clewell, G. H. Stickney.

Mr. C. L. Law, vice-president, called the meeting to order at 2:30 p. m.

Upon recommendation of the Finance Committee vouchers Nos. 2452 to 2488, totaling $1,155.65, were authorized paid.

Resolved, that the Finance Committee submit a special report to the president which shall set forth the financial requirements of the society and the amount of additional income desired from each of the various sources of revenue, together with suggestions as to possible reductions in expenses.

Upon recommendation of the Board of Examiners the following applicants were elected.

To the grade of member, 1.

To the grade of associate member, 9.

Four resignations were accepted with the usual provision that a resigning member may be informally reinstated should his resignation be withdrawn before the end of the fiscal year.

Progress reports were received from the following committees: (written) Administrative Committee on Lectures, Committee on Education, and Midwinter Convention Committee; (oral) Committee on School Lighting, and Papers Committee. In reporting for the Committee on School Lighting, Mr. Luckiesh stated that a draft of the Code of School Lighting prepared by his committee had been submitted to the Committee on Lighting Legislation for consideration. Mr. G. H. Stickney reported informally for the Committee on Lighting Legislation.

Oral reports on section activities were received from Mr. C. L. Law, vice-president, representing the New York Section; Mr. C. A. B. Halvorson, vice-president, representing the New England Section; and Mr. C. O. Bond on behalf of the Philadelphia Section.

The following committee appointments were confirmed: *Administrative Committee on Lectures*—Clarence L. Law, H. K. Mohr.

The question whether the Society should give to applicants not members of the Society copies of its list of members or mailing list was discussed. It was decided that each applicant be advised that the cost of such a list is $5.00, this price to include a certain amount of advertising in the TRANSACTIONS. The general secretary was given discretionary power to apply this ruling.

A special committee reported on a successor of Joseph Langan, assistant secretary, resigned. It was resolved that the Council instruct the general secretary to offer the position of assistant secretary with a salary at the rate of $1,800 a year to Mr. C. D. Fawcett. The committee was discharged with thanks.

A meeting of the Council was held May 11, 1916, in the general offices of the Illuminating Engineering Society, 29 W. 39th St., New York, N. Y. Those present were: E. M. Alger, C. O. Bond, H. Calvert, Geo. A. Hoadley, Clarence L. Law, C. A. Littlefield, general secretary; L. B. Marks, treasurer; Preston S. Millar, J. L. Minick, A. S. McAllister, J. Arnold Norcross. Upon invitation, Geo. H. Stickney.

Mr. Geo. A. Hoadley, vice-president, called the meeting to order at 2:55 p. m.

Upon recommendation of the Finance

Committee vouchers Nos. 2489 to 2525, totaling $1,155.67 were authorized paid. Mr. Calvert, chairman of the Finance Committee presented a report showing the financial standing of the Society. He pointed out that unless there was a curtailment of the TRANSACTIONS expenses that account would exceed its appropriation of $4,000 for the present fiscal year.

In accordance with the above-mentioned suggestion the following committee was appointed to see that the TRANSACTIONS expense was limited as much as possible for the rest of the year: A. S. McAllister, chairman; G. H. Stickney and C. H. Sharp.

Upon recommendation of the Board of Examiners the following applicants were elected subject to their application being completed in accordance with the constitutional requirements:

To the grade of member, 4.

To the grade of associate member, 5.

Two resignations were accepted with the usual provision that a resigning member may be informally reinstated should his resignation be withdrawn before the end of the fiscal year.

Progress reports were received from the following committees: (written) Administrative Committee on Lectures, Papers Committee, and Committee on Reciprocal Relations with Other Societies.

The matter of the Society being responsible for a session at the coming Convention of the American School Hygiene Association was referred to the Committee on Papers.

Oral reports on section activities were made by Mr. C. L. Law, vice-president representing the New York Section; Mr. J. L. Minick, vice-president representing the Pittsburgh Section; and Mr. Geo. A. Hoadley, vice-president representing the Philadelphia Section.

The following committee appointments were confirmed:

Administrative Committee on Lectures: F. H. Gale.

Committee of Election Tellers: Norman Macbeth, chairman; W. A. D. Evans, H. T. Owens, A. L. Powell, and E. F. Tweedy.

Section Meetings.

CHICAGO SECTION

May 25, 1916, in the Gold Room, Congress Hotel. Instead of having the regular monthly meeting of the I. E. S. the Board of Managers accepted the invitation of the Commonwealth Edison Section, N. E. L. A., to attend the meeting of the Commercial Section during which the following papers were presented: Report of Committee on the Aspects of Highway and Municipal Lighting by T. F. Kelley; Report of Committee on Industrial and Yard Lighting by Oliver R. Hogue; Lecture, "Lighting by Product or Buy Product" by Wm. A. Durgin.

NEW YORK SECTION

May 11, 1916, Engineering Societies Building, 29 W. 39th St., New York, N. Y. Papers: "Problems in the Design of Lighting Fixtures" by Stepan De Kosenko; "Observations on Lighting by a Glassware Manufacturer" by A. Douglas Nash. Attendance 220.

PHILADELPHIA SECTION

May 19, 1916, in the Engineers Club, 1317 Spruce St., Philadelphia, Pa. Paper: "Educational Aspects of Illumination" by Prof. F. K. Richtmyer.

PITTSBURGH SECTION

May 12, 1916, at the Hof Brau, Cleveland, Ohio. Papers: "White Light for Moving Picture Photography" by W. R.

Mott; "The Photography of Lighting Installations" by W. E. Brewster.

New Members.

At a meeting of the Council held April 13, 1916, the following applicant was elected a member:

MEREDITH, H. C.
Illuminating Engineer, Ivanhoe-Regent Works of G. E. Company, East 152nd St., Cleveland, Ohio.

At a meeting of the Council held May 11, 1916, the following applicants were elected members:

FAWCETT, CHARLES D.
Instructor in Electrical Engineering University of Pennsylvania, Philadelphia, Pa.

FEIKER, FREDERICK M.
Editor, Electrical World, 239 West 39th St., New York, N. Y.

PALMER, RAY
Vice-president and General Manager, New York & Queens Electric Light & Power Co., 444 Jackson Ave., Long Island City, N. Y.

WIRT, CHARLES
President and Engineer of Wirt Co., Armat and Lena Sts., Philadelphia, Pa.

Transfers to Grade of Member.

The following associate members have been transferred to the grade of member:

HAMMER, WILLIAM J.
Consulting Electrical Engineer, 153 West 46th St., New York, N. Y.

MCLAUGHLIN, JOHN C.
Manager, Commercial Department, Potomac Electric Power Co., 231 14th St., N. W. Washington, D. C.

New Associate Members.

At a meeting of the Council held April 13, 1916, the following applicants were elected associate members:

FRANCK, CHARLES
General Manager of Sales, Holophane Glass Company, Inc., 340 Madison Ave., New York, N. Y.

HARE, KENNETH ROSS
Associate Editor, Railway Electrical Engineer, 233 Broadway, New York, N. Y.

HENRY, ARTHUR S.
Sales Engineer, Comstock Associate Company, 101 Park Ave., New York, N. Y.

HOBBIE, EDWARD H.
Mississippi Wire Glass Company, 220 Fifth Ave., New York, N. Y.

MCDOUGALL, GEO. K.
Consulting Electrical Engineer, 83 Craig St. W., Montreal, Canada.

RASIN, UNIT
District Manager, Westinghouse Lamp Company, 1411 Widener Bldg., Philadelphia, Pa.

TABB, J. W.
Lamp Specialist, Western Electric Company, 6th and Cary Sts., Richmond, Va.

TROLAND, LEONARD T.
Instructor in Psychology, Harvard University, Nela Research Laboratory, Nela Park, Cleveland, Ohio.

WENIGER, WILLIBALD
Physicist, Nela Research Laboratory of G. E. Company, Nela Park, Cleveland, Ohio.

At a meeting of the Council held May 11, 1916, the following applicants were elected associate members:

BEAM, J. C.
Lamp Specialist, General Electric Co., Schenectady, N. Y.

BECK, WILLIAM H.
Power and Maintenance Engineer, Crown, Cork & Seal Co., 1511 Guilford Ave., Baltimore, Md.

DICK, JAMES F., JR.
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Chemist, Roessler & Hasslacher Chemical Co., Cor. Fayette and High Sts., Perth Amboy, N. J.

MASON, MAYNE S.
Instructor in Electrical Engineering, Rutgers College, New Brunswick, N. J.

Personal.

Mr. C. D. Fawcett, formerly instructor in the Electrical Engineering Department of the University of Pennsylvania, has been appointed Assistant Secretary of the Illuminating Engineering Society, to fill the position made vacant by the resignation of Mr. Joseph Langan.

Obituary.

On May 5, 1916, Henry Floy, consulting engineer, 120 Broadway, New York, N. Y., aged 49 years.

Mr. Floy was graduated from Cornell University in 1891 and from Wesleyan in 1899. He gained national reputation at his invention of the first underground high tension electric transmission, and at the publication of his various works, among them being "The Valuation of Public Utility Properties," "High Tension Underground," and "Value for Rate Making."

Mr. Floy was appointed on the Arbitration Committee of the Colorado Springs Controversy, and he was a member of the Engineers' Club, The American Institute of Electrical Engineers, and The National Electric Light Association.

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THE RELATION OF LIGHTING TO ARCHITECTURAL INTERIORS.*

BY MORGAN BROOKS.

Synopsis: This paper urges effective correlation between the design of an interior and its illumination. It also indicates some methods for lighting interiors with this object in view. The following points are briefly discussed: Non-uniformity of illumination. Art obscured by monotonous lighting. Undesirable dimensions alterable in appearance by skilful lighting. Effective controlling of contrasts—example, the lighting of a colonnade. Lighting in a residence made attractive. Alternative lighting illustrated. Advantage of directed light; its production by an oval or elongated type of semi-indirect bowl. Grooved ceilings for special distribution of inverted rays.

At first it appears surprising that an architect who has successfully produced a beautiful interior should relegate the lighting thereof to an uninspired subordinate, or even leave it to chance, with results often so inharmonious as to obscure his art. Doubtless this is partly due to the fact that the architect did not visualize his illumination with his interior plan, and will not or cannot give it afterthought, and partly because he is not seriously disturbed by the incongruous lighting of an interior which appeals to him as beautiful with or without light, so powerful is his original idea. Probably one specially trained in illumination, who has artistic perceptions, and is eager by skilful lighting to point out to others the beauties of an architectural design, and to soften any defects, will obtain better results than could the architect himself.

It has been customary enough for architects to design their specially built gas and electric fixtures, but it will be agreed that,

* A paper read at the mid-winter convention of the Illuminating Engineering Society, New York, February 10, 11, 1916.

as a rule, the harmoniousness of these fixtures is felt more by day than by night. There is a certain antique conventionality inherent in a porcelain-candle miniature-lamp design that makes it hopeless to derive therefrom adequate modern flood lighting.

The rapid advance in lamp making which gives us powerful units also necessitates new methods of indirect or concealed sources to avoid glare. Yet possibly the successful attempt to introduce light from nowhere has outdone itself, as the logical mind is baffled by the absence of a source of light.

Not only is it a satisfaction to know whence light emanates, but it is artistically pleasing to have illumination non-uniform. Indeed non-uniformity is a neglected means of success in architectural appreciation by light. When we admire a cozy-corner in a home, its attractiveness results from its being set apart from the rest of the room by its furnishings. A table lamp with an attractive shade provides good illumination but over only a limited area. Take away the table lamp and flood the corner with superfluous light, and all coziness is gone.

In a similar manner much of the artistic taste in the design and furnishing of a room is nullified by immoderate or by monotonous lighting. When a room is completely lighted it is grasped at a glance, and maintains no interest. If only the center table is illuminated, there is opportunity for the play of the imagination in the darker spaces, and the room appears larger. Of course, if the entire room is to be occupied, as is a concert hall, it must be completely lighted; but even here the effort to obtain uniform illumination may result in diminishing the attractiveness of the room. Given a concert hall that is unduly long, with a platform at one end and entrances at the other; if evenly lighted the first glance discloses the full length of the hall and the extreme distance to the platform from the rear. Now let the stage be overlighted, the center only moderately lighted, and let the rear, under the balcony, have an intermediate illumination. On entering, the stage is conspicuous, and the middle portion of the hall loses a few rows of seats, bringing the rear seats decidedly nearer to the stage. Of course, the differences must be skilfully managed to show no sharply dividing lines, and the minimum must be to program-reading standard. When such irregular illumina-

tion has a valid psychological basis it proves acceptable, although often unnoticed. To diminish the length of a hotel corridor this scheme of graded lighting is inadequate; but if the mid-length is well lighted especially by visible lamps, while the portion beyond is less brightly lighted and from concealed sources, the ordinary vision hardly goes beyond mid-length.

To take another case, a wide room will appear longer when the side walls are illuminated more than the ends, which then recede. The effect is enhanced if the ceiling-wall line is somewhat indeterminate, as the eye judges not merely by illumination but also by geometrical outline. Experiments show that a difference of the order of 10 per cent. may be produced in the apparent distance of a wall by altering its illumination.

Photographic art teaches us that pleasing contrasts may be produced by proper management of light, suggesting possibilities in artificial lighting of interiors often artistically superior to that of daylight. Fairly bright illumination is necessary to bring out a color scheme, while if form alone is to be shown, contrasts may be increased or diminished by throwing more light on the brighter surfaces or on the darker. In this way desirable contrasts may be enhanced, and undesirable ones subdued. Thus to display a colonnade the columns should be accentuated by illumination if naturally bright; but if dark, should be silhouetted against a well lighted background. Shadows should be produced. For extreme conspicuousness they should be made to run quartering by a 45° position of lamps. On the other hand objectionable pillars can easily be made inconspicuous, if they are rectangular, by dimly illuminating their surfaces to agree with a dull wall behind. In the case of round columns only perfectly diffused lighting will cause their rotundity to merge into the background. Pilasters, always an architectural embellishment, should be brought out by throwing their projecting sides into comparative darkness.

Any artistic feature of a house, such as an oil painting, a choice bit of furniture or a handsome stairway may be emphasized by superior illumination, just as a masterpiece of sculpture in an art gallery is specially lighted. Care must be taken, however, not to overdo this, or an exaggerated theatrical spot-light effect may

result. These effects depend wholly upon relative illumination, and are equally possible with dim or brilliant general lighting. The beauty of a landscape is enhanced at sundown by the lengthening shadows of directed but diminishing light. Modern powerful high-efficiency lamps tend toward a lavish use of light often in entire disregard of artistic proportionality, imitating midday glare.

Psychological as well as artistic considerations suggest varying the illumination progressively for one entering a house. Finding the vestibule brighter than the entrance steps, the hall brighter than the vestibule, and the reception room brighter than the hall, a guest is insensibly directed by the increasing light in a hospitable manner. Where a valid reason for illumination differences exists, dependent on the use and the relative importance of the various rooms, pleasure is felt in the lighting interpretation, even when the means are not recognized. When the conditions are disturbed, perhaps merely by failure to replace a burned-out lamp correctly, the discord is felt by one at all sensitive to harmony in illumination.

Much thought is required to adapt lighting to the varying uses of a house. The best preliminary to lighting plans is to make an imaginary tour of the building with its owner or occupant, asking what the color scheme will be, what vistas must be kept unobstructed, the purpose of this room and that, and how they will be furnished. Beginners in illumination often overlook the light absorption by dull portieres and furniture, which darken a room. The quantity of light required increases with surface area. A rectangular desk shoved into a corner adds nothing to the room surface, but if set out in the middle of the room all its vertical sides are additional. Thus, in a public library, book stacks often more than double the area requiring illumination.

A good example of alternative lighting of a room adapting it to different demands, is seen in the flood lighting of a hotel dining-room for use at a general banquet, and in the cozy table-lamp transformation with meager general illumination, when it is desired to provide as many separate tables as possible for private parties. Indeed, the manager of a large hotel remarked that when the dining-room was thus lighted it was surprising how loudly

the guests talked, as if no one were within hearing! Similarly a public reading room may have table lamps suggesting a privacy conducive to study, or may have the blaze of general lighting satisfactory for desultory reading, points of view justifying the combination of both methods.

Completely diffused lighting is wearisome, as evidenced in "white kitchen" restaurants, and there is one advantage in partially directed light not always recognized. Eye fatigue is relieved by change in illumination which causes a change in the adjustment of the eye muscles. When reading by direct light a slight movement of the paper produces such relief, perhaps unconsciously; but with diffused lighting no relief is possible. This explains why in inverted lighting the effect is better with relatively dark walls, as they absorb the horizontal rays, and the light comes only from above.

The well known unsatisfactory combination of artificial illumination and daylight is in part due to the mingling of horizontal and vertical rays, although color difference is also important. Architects avoid cross window lights, yet often specify strictly bracket lighting for a room, with brackets on every wall. When all are in use simultaneously there is objectionable cross-lighting and glare.

Freedom may be urged in the placing of fixtures unsymmetrically except in rooms of extremely formal symmetry. Doors and windows are seldom regularly placed. Furniture must be arranged with reference to doors and windows; why not locate lighting fixtures with direct relation to the furniture? In factories utility governs location. In an artistic interior appropriateness governs, and this includes use as well as beauty.

Since the common arrangement of inverted lighting produces symmetrical and almost uniform illumination, it may seem that the artistic variation proposed would demand a return to direct lighting with its glare. It is true that extreme differences may require direct lighting, but semi-indirect and even direct lamps may be made much less diffusing than usual. There is opportunity in the development of oval or even boat-shaped bowls in semi-indirect lighting for sending out most of the light laterally. Moreover, it is possible to design one side of such elongated

bowls for superior brightness, without diminishing their artistic appearance, and thus give the unsymmetrical light distribution suited to special needs.

A new method of directing inverted rays is found in a grooved ceiling. The resultant distribution depends upon the lamp reflector as well as on the shape of the grooves. With V-shaped grooves the locus of maximum floor illumination is not directly under the fixture but is an ellipse with major axis transverse to the direction of the grooves; while, strangely enough, loci of lesser illumination are elliptical figures, whose major axes are longitudinal. With a V-ceiling a single row of inverted lighting units placed somewhat nearer together than usual, will serve a wider room than with a smooth ceiling. Also the brightness of the ceiling immediately over the lamp is reduced. A grooved ceiling will direct downward much light that is now wasted on upper walls, but the use of such a ceiling is suggested for directing light rather than for economy. Since distribution from a grooved surface depends on the shape of the grooves, independently of their size, the grooves may be minute, when the appearance would not differ noticeably from the usual ceiling. Such markings can probably be impressed upon fresh plaster at moderate expense, and in steel ceilings it is evident that fine grooves can be manufactured if demanded.

Whether these means or others are adopted, there should be a reaction from the too complete diffusion of modern inverted lighting, with appreciable gain in artistic effect.

DISCUSSION.

MR. J. R. CRAVATH: The occasional desirability of localized lighting and non-uniformity as exemplified by the coziness of a table lamp cannot be denied. At the same time there are many interiors where the same coziness would be termed gloominess. This is also somewhat a matter of taste, temperment and previous environment. Completely diffused lighting in white kitchen restaurants may be psychologically wearisome and unartistic to some people but I doubt whether there is any evidence that it is physiologically wearisome to the eyes. The brightness contrasts presented to the eye are likely to be of such a low order as to

be very comfortable. We are apt to consider that indirect and diffused lighting systems give much greater uniformity than is the fact. We used to hear it said frequently that indirect lighting gave absolute uniformity and therefore it was tiresome, but we know now that this statement will not hold in ninety-nine out of every one hundred cases. I do not agree that indirect lighting gives a better effect with relatively dark walls. In fact the effect is best, both hygienically and artistically, with light colored walls, because with very dark walls the preponderance of downward light is so great as to cause unpleasant shadows. Dark walls also emphasize the contrast of brightness between the ceiling and walls which frequently is not a good thing.

I would consider it unfortunate if the statements in this paper were to lead to the use of brighter or less dense bowls for semi-direct lighting in order to secure more positive direction to the light. The use of semi-direct bowls of too light density is one of the things some of us are working the hardest to do away with in the interests of public eye hygiene.

Mr. S. E. Doane: I think that we can recognize in this paper of Professor Brooks, just the kind of paper we should have. We need papers written by men of great scientific education, but written in a very clear and simple manner.

Professor Brooks has suggested one of the very greatest needs of our Society in his paper, not in a specific sense but rather by way of illustration, very much as Professor Munsterberg illustrated his meaning in a recent article on moving pictures, when he said that one of their greatest values or perhaps the greatest value is that they make us think, as we almost unconsciously place in the mouths of the actors the words that we believe they should utter under the circumstances. Every society, every profession, when they are young, possess in common some of the qualities which we, as individuals, possess when we are young, when we are graduated from college. At that time in our lives we are specialists, but not in the same sense that we are later. It probably may be true that we gain more specialized knowledge as we grow older, but a larger percentage of our total knowledge acquired with years experience is (or should be) along broader lines. The tendency of late, has been to apply this special knowledge more and more directly to the benefit of the people as a whole.

Professor Brooks has asked us in this paper to satisfy the public's needs. The public may realize, in an indefinite way, the short comings of a lighting installation, but it has not the specialized knowledge to enable it to tell us just what it wants. It is our duty to know. He speaks about a room being attractive and cozy when lighted by a table lamp, but we must not forget that the next night there may be a card party in this same room and that the soft localized illumination one night would appear dull and inadequate the next. The card party may be followed by music, the young people may wish to take up the rugs and have a little dance, so we must think of all these things in the illumination of the room. It seems to me that the architect and decorator should work on this problem, should study the needs of the people, they should specialize and bring to us a broader knowledge and a wider education by which we can do the specialized work along our line.

THE POSSIBILITIES OF STAGE LIGHTING TOGETHER WITH AN ACCOUNT OF SEVERAL RECENT PRODUCTIONS.*

BY BASSETT JONES.

Synopsis: Stage lighting demands a diversity of color and intensities not met with in any other class of illumination. This paper deals with the requirements of certain specific examples; developing the color schemes, indicating the relative intensities and positions of the illuminant with respect to the objects illuminated, and describing some novel units for the footlights, border lights and flood lights. A sample lighting schedule in agreement with the scenario and action play forms an interesting part of the paper.

I.

In the *Electrical World,* beginning in the issue for July 31, 1915, vol. 66, No. 5, I published a series of articles dealing with "Mobile Color and Stage Lighting." At a meeting of the New York Section of this Society held in the Hewlett-Basing Studios on May 8, 1912, the method of stage lighting devised by me for use in the restaging of "Peter Pan," together with its relation to the particular type of dyed cloth and gauze scenery developed by Messrs. Hewlett and Basing, was demonstrated on a half scale stage.

The present paper is to be taken as a sequel or appendix to "Mobile Color and Stage Lighting," and will deal with specific examples and with certain modifications of the general system that have proved expedient. Such changes are entirely of method and not of apparatus. The original devices designed and built in the summer of 1911 are still in use after four years of road work.

But first let me state most emphatically that I make no pre-

* A lecture delivered at the mid-winter convention of the Illuminating Engineering Society, New York, February 10, 11, 1916.

tentions as a theatrical expert. My work in this field, such as it is, has been strictly for my own amusement. It has been the satisfaction of a hobby—as other men play golf, collect antiques, or paint pictures. I might add that my engagement in the practise of illuminating engineering is also an appendage to what, from my personal viewpoint, is the mother profession of electrical engineering. My strictly and purposely limited professional connection with the stage arose through an accident and probably shall remain so limited.

In the use of light as an adjunct to architectural and decorative design, my father taught me to avoid the bizarre—the Coney Island and typical Broadway 'stunt.' In stage lighting I have learned from both Mr. Hewlett and Mr. Greenley to conceive the effect as purely decorative—more or less conventionalized—and as far removed from the crude realism of a Winter Garden or Hippodrome 'show,' as a Whistler's "Battersea Beach" is from a colored photograph. The stage is no more the place for a museum-like reproduction of nature than is the artist's canvas. So much to make clear my point of view.

Perhaps you will pardon so much personality, but I do not desire to stand before you in the guise of a theatrical man; for such I am not. And, further, when the chairman of your Papers Committee asked me to prepare a paper on 'The Possibilities of Stage Lighting,' it occurred to me that the use of the word 'possibilities' indicated, in truth, the crux of the whole question. The possibilities of stage lighting must indeed remain a 'permanent possibility' until there occurs a change, both in the public attitude and in the attitude of those professionally connected with the practical phases of the stage. The possibilities of stage lighting will remain possibilities just so long as there are possibilities in stage setting. The two are inseparable. To show you just what I mean, lacking a properly set stage with which to work, is impossible. I am, therefore, forced to fall back on most unsatisfactory black and white cuts and, for lack of funds, uncolored lantern slides. However, there are a number of you who have doubtless seen "Peter Pan" in his new setting. This production in its essential freedom from realism, its quiet decorative character, and its exquisite chromatic quality illus-

trates most perfectly the sort of stage setting and lighting for which I appeal. If you have not seen this wonderful little play, then I am at a loss so to use my poor words that they may conjure up for you some picture of the reality which my illustrations paraphrase. The best compliment I ever heard paid to Miss Adams' good taste was in connection with the lighting of "Peter Pan." A man, whose judgment in Chinese porcelains and electrical matters I value, told me that he could not see anything so wonderful in it. It was very quiet, it seemed to him, and left no marked impression. This anecdote serves, perhaps better than anything else, as a test for my argument.

Nothing on the stage can change from its present crudity until both public and artists demand it so. Yet the desire is half the battle won, if backed by purpose. And I wish to draw your attention to the efforts of a little band of players heroically struggling with financial problems, yet freeing themselves from the trammels of precedent enough to do what only a few strong hearts have attempted.

I bid for your support of the Washington Square Players. This little company of enthusiastic artists have given their all for the sake of an ideal. And this is truly the mark of the highest heroism. Here you will find decoration the keynote of the settings even though the monetary limitations are obvious. I count it a privilege that this company has given me an opportunity to assist in the solving of their problems purely for the pleasure of getting something done, however little it may be.

II.

In the Band Box Theatre, I think we have solved the problem of the footlight. I had believed some years ago, that these seemingly unnatural and distorting sources of illumination could be relegated to the scrap heap. Since, I have learned the error of my ways, and am convinced of the importance of the 'foots,' now that I have seen the unfortunate results of their abandonment. I, too, had imagined the stage lighted only from above and this we tried—I think in 1913—but only experimentally. True, the foots may sometimes be omitted from the lighting scheme—as in the first part of the fourth act of "Peter Pan," but even here, only during the tableaux-like appearance of the pirate ship.

The trouble is not in the foot-light *per se.* It is a case of *modus in rebus.* With purely overhead lighting the facial shadows are too pronounced because they are not luminous. The footlights should serve the purpose of relieving this contrast—not to reverse the intensity. Furthermore, remember there may be little if any light coming through the proscenium arch to the stage, unless there be 'front of the house' spots or floods.

So, too, depending on the situation the foots require flexibility. Usually there is a locus of action in the scene. Here the maximum of illumination is required, both from above and below. There is required, therefore, a sectional footlight controlled in sections, and portable, so that it may be concentrated at one side or the other. A continuous foot trough is neither necessary or advantageous. Rather the foots should be in the form of groups of two or three light units, the groups so arranged that they can be moved longitudinally from below, and the maximum intensity directed at will.

Again, the glare from the exposed filaments is a source of trouble. This can be obviated by setting the filaments horizontally, or nearly so and enclosing each lamp in a deep bowl-shaped metal reflector of the extensive type. At the Band Box Theatre we use two unit groups (Fig. 1) each group consisting of two 100-watt lamps in baked white enamel reflectors, giving two colors—light blue and pale amber, or white and amber. As the foots are intended to light the artists down stage and *not* the scenery, these colors are usually sufficient. In fact at the Band Box we have, up to the present,—the third series of productions—used nothing but light blue and light amber in foots and main border, as these two colors, unsaturated, and used synthetically, give a very good quality of light for the action and for general color value. The front of the house lights and side floods are white or any other color required to accent particular values. Miss Adams uses four unit footlight groups in aluminum finish reflectors with 100-watt stereopticon lamps and color filters in white, amber, rose and green.

Footlights arranged in this way are readily portable, and do not light the front stage platform excessively. At the Band Box Theatre there is nothing to lead the uninitiated spectator to believe that the foots are lighted; not even in the appearance of the

actors themselves, provided, of course, that the correct balance in intensities is used.

As for the front of the house lights, they too, are an unfortunate necessity. I have tried to do away with them but without success. Mr. Belasco has substituted for them a border concealed behind a bowed hood projecting out into the auditorium from the proscenium. But this, of course, like the sky dome, is applicable only to stages built with this in view, and while no balcony lights are used the result is not altogether satisfactory as the angle of light flux is too steep and, without the foots, exaggerates facial shadows. It well nigh blots out the features when hats are worn by the performers. At least so it seemed to me as a spectator, and, as I have heard others say the same, I presume that my impression was correct.

The prime difficulty is that the proscenium arch is a black hole so that any object facing it normally receives no light from this direction and if well down stage is sharply silhouetted against the relatively brilliant background.

With considerable success, Mr. Barker has used a number of small spot lamps mounted on the face of the balcony. Miss Adams used the same multiplicity of small spots some years ago. The spots were set in the auditorium ceiling in such a position that they were obscured from the audience, and interestingly enough used Nernst glowers as a light source, thus somewhat closely approaching the ideal form of filament for projector work. The results were successful, but the apparatus was expensive in first cost and maintenance. It also required care in adjustment and structural facilities that were not always available when on the road.

Miss Adams now uses four 20-in. (50.8 cm.) parabolic reflector spots employing concentrated filament type C lamps of special construction. The apertures of the reflectors are equipped with a system of concentric louvres to kill the direct 'spill' light (Fig. 2).

At the Band Box Theatre we first tried to avoid the use of front of the house lights by special arrangements of the foots and by using floods on each side of the proscenium arch. Later front of the house lights similar to those used by Miss Adams

were installed with the addition of diaphragms to confine the light to the desired region of the stage. The difficulty encountered in using such lights down low as at the Band Box where there is no balcony, or on the balcony face, as used by Mr. Barker, is that they light the scenery whereas their only purpose is to light the performers down stage. To counteract the flattening effect of fronts and foots, and to illuminate shadows and lend them color, we have used light blue diffusing floods from high up on each side of the proscenium arch.

There is nothing on the stage so unwieldy or so inefficient as the common trough border light. For this we have substituted a line of white enamel or aluminum finish steel reflectors of various shapes depending on conditions, usually 30-degree aperture focusing at the main border just back of the proscenium, and intensive type in other cases.

The most successful arrangement has proved a main border as described and the up stage borders of 20-in. (50.8 cm.) aperture reflectors using 400-watt special type 'C' lamps, and aluminum finish diffusing reflectors with different colors. Usually two borders of this type each with two such floods are enough. The disadvantage is the space required in the scenery loft, but, if the space can be found, the advantage is material. The total overhead equipment used by Miss Adams consists of a main border of sixteen 100-watt units, two side floods and two borders of two 400-watt units.

At the Band Box we use a main border of three parabolic strips each containing six 100-watt stereopticon lamps (Fig. 3), two side floods of 400 watts each, and two 'basket' border units of 1,000 watts (Fig. 4), each of a different color.

The border supports are of iron pipe, the larger units hung from the pipes by chains (Fig. 5), so that they can be set in any location on the pipe and the maximum flux directed in any direction. This gives great flexibility in the lighting arrangement.

The pipe for the main border of reflector units is provided with a tee for each unit with a projecting stud to which the unit is fastened by a thumb screw (Fig. 6). Two or three circuits are run in the pipe hanger to which the units are plugged by two pin connectors. The entire border can therefore readily be disas-

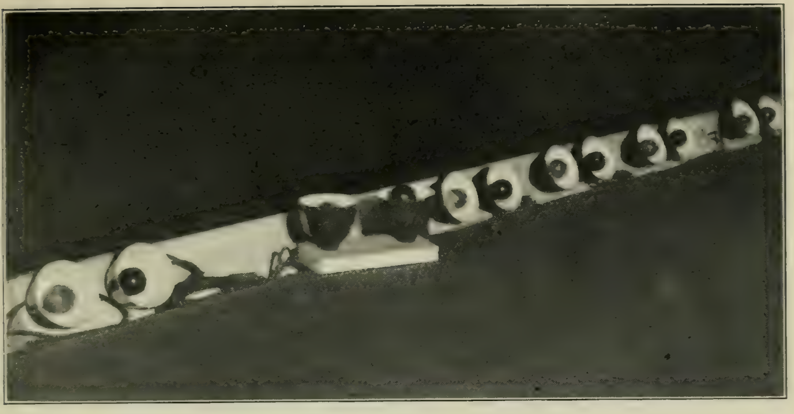


Fig. 1.—Footlights at the Band Box Theatre, New York.

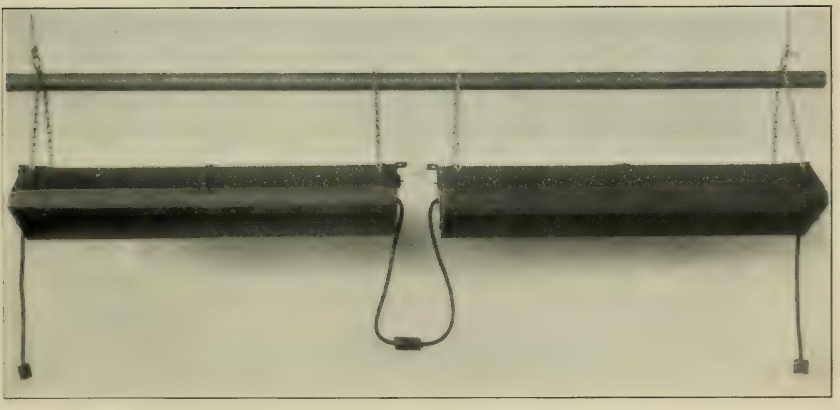


Fig. 3.—Parabolic strips used as border.

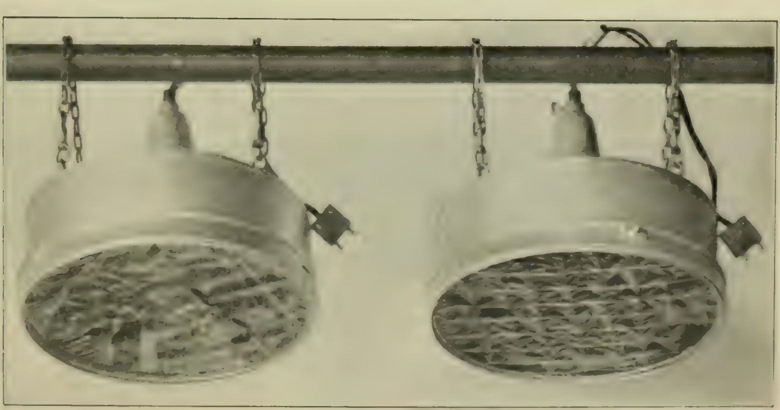


Fig. 5.—Parabolic floods used as border.

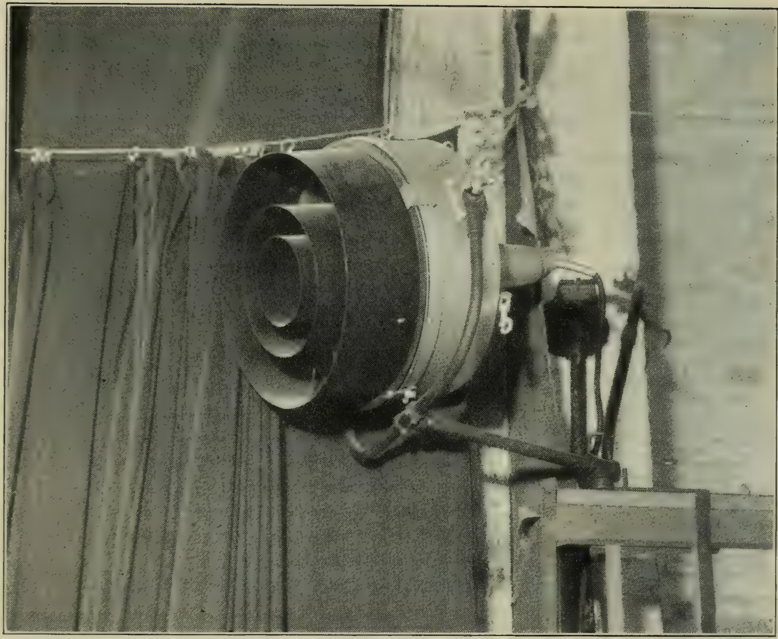


Fig. 2.—Parabolic side floods at the Band Box Theatre, New York with louvres. Color holders slip in between louvres and casing.

Fig. 4.—Basket unit for 1000-watt lamp,

sembled for shipment. As space at this point is valuable every effort has been made to keep down the size of the equipment even to omitting any protecting hood. The reflectors can be easily replaced in any electrical supply house.

We have tried glass reflector units, but they are too fragile for road work. Furthermore a protecting hood of sheet iron is absolutely essential in spite of the space it occupies. I have seen a stage hand accidentally thrust a ladder under the protecting hood and smash several such units showering the stage with glass. The lamps are bad enough in this way, but they are at least given some sort of protection by the steel reflectors.

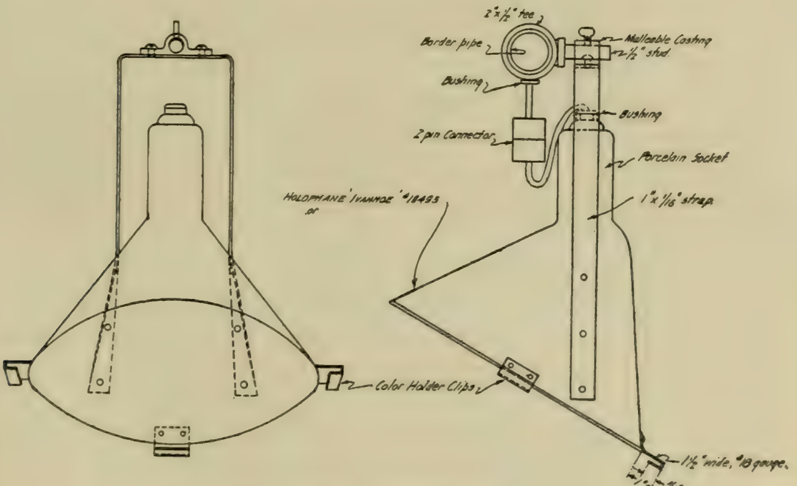


Fig. 6.—Unit border

Furthermore, glass mirror gives a 'hard' reflection and a corresponding glare that may be marked where high finish surfaces are required in the scenery and where grease is used in make-up. While the control of the distribution of brightness is not so perfect with the more diffuse reflecting surfaces, such as baked enamel or etched aluminum, the quality of the light, in our opinion, is much better.

In designing stage equipment one must always keep in mind the prime necessities of space, strength, and ease of mounting and taking down for shipment. Everything must pack compactly so as to take up as little baggage car space as possible.

The ideal is a five-scene production to a car. No single piece, not even a back drop, should be too heavy or bulky, when packed, to be handled by a single man. Scenery structure-frames, stairs, etc., by the exercise of a little ingenuity quite foreign to the average stage carpenter or scene builder, can be arranged to fold into a compact block. Engineering of this sort produces a large financial return, but is not generally appreciated.

A more detailed account of much of the equipment will be found in the articles in the *Electrical World* to which reference has already been made. In these articles will also be found a somewhat lengthy account of color in stage lighting which will therefore be referred to here only in passing.

Recently we have experimented successfully in the lighting of back drops by using a series of 20-in. (50.8 cm.) aperture parabolic reflector casings equipped with diffusing reflectors and 300-watt type C lamps set on a stand along the bottom of the drop and facing upwards. These take the place of the parabolic strips and are easier to handle in road work. They require greater spacing between drops however.

The wiring for a system such as this and the switching arrangement required are, of course, quite different from anything found in the usual theatre. Miss Adams carries her own portable wiring, even to the front of the house lights, but the system, being so simple, is easy to install and take down. She also carries her own switch board and dimmer bank of eight plates—a very much simpler switchboard than one usually finds. (Fig. 7.) In this design there is no novelty.

By using a transfer switching system the number of dimmer plates can be materially reduced. I recently designed and installed a permanent board of this type working much after the manner of a jack type telephone switchboard.

III.

The system of stage lighting described above is peculiarly flexible and necessarily so since it is merely a new palette added to the equipment of the stage artist. It represents, in effect, the various brushes and pigments that experience has proved essential. And, as the painter makes shift to obtain wonderful and complex tonal quality with a few colors, so an enormous variety

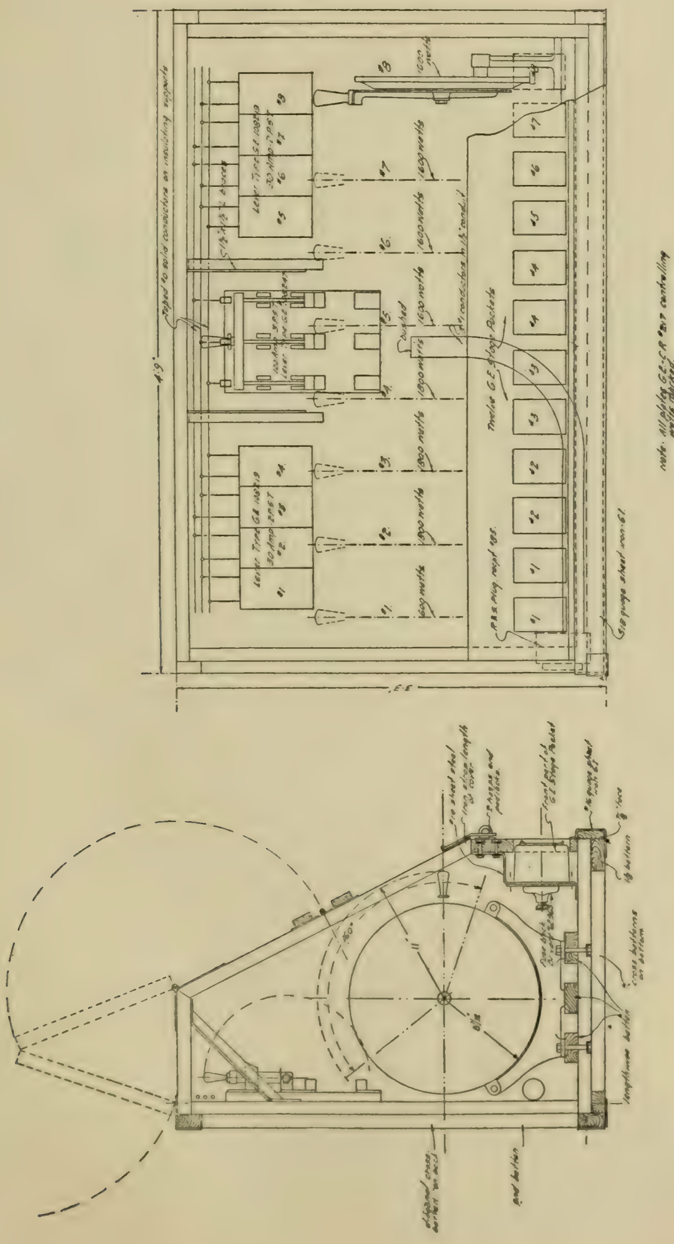


Fig. 7a.

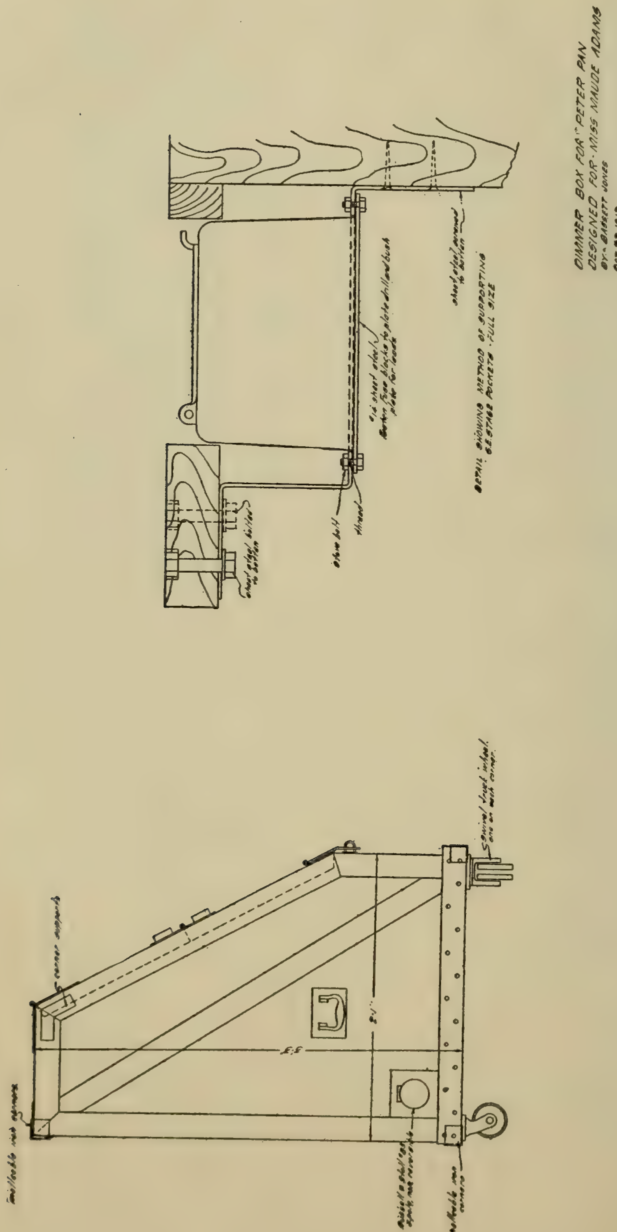

DIMMER BOX FOR "PETER PAN"
DESIGNED FOR MISS MAUDE ADAMS
BY BASSETT JONES
OCT. 22, 1912
DETAIL SHOWING METHOD OF SUPPORTING
ON G.E. STAGE POCKETS · FULL SIZE

Fig. 7b.

of results can be produced by a few pieces of properly designed stage lighting equipment.

I am absolutely opposed to 'effect' on the stage—to the 'spot,' which I am glad to say has been relegated to the burlesque and musical 'show'; to mechanical lighting 'stunts' of all kinds which tend to reduce the stage to what I have called 'a mechanic's universe.'

Nor is it enough to merely flood the stage with light. The direction, quantity and quality of the light count for much. By direction, I mean the effect of the light in giving perspective and shadow, and is therefore, of great moment in the picture. The best scene can be killed by distortion. Accenting the wrong high-lights is like bad pronunciation in speaking—it jars.

Possibly there has never been a case where asymmetric lighting of the stage did not have the best of the argument. Sometimes a silhouette is quite as interesting—even more so—than a full face effect. Whatever is done, remember the entire object is to paint into the scene just the atmosphere that will best serve to accent the acting situation whether that be farcical or tragic, or merely the presentation of an exquisite picture, dancing, music, or what not.

At earlier lectures before this Society running as far back as 1910, I have showed, by the aid of a color and shadow booth, how extraordinary was the distortion of form produced by unnatural direction of intensities or excessive diffusion. How then, is it possible for the observer to gather the finer nuances of feeling or emotion from a scene when the sensory material upon which the physiological side of the emotion is built, come to him all out of form and proportion? He is so busy unconsciously sorting out and correcting impressions that his mind simply passes over all of the finer elements which merely slip through the sieve of memory and are lost.

As to quantity, generally one can not see for the light. Chromatic value cannot be obtained at high intensity. One or the other may be obtained, but not both. With the use of high intensity comes the use of garish and crude color arrangements, for the color must fight for its life. Nothing fine can be done under such conditions; and the poor actor! How can he be expected to

show his emotions when his eyes are blinded and his facial muscles paralyzed?

Upon quality depends a great deal—whether the scene looks hard or has atmosphere. This is largely a matter of distribution and diffusion. Shadows must be luminous and free from sharp edges. There must be no marked focussing—nothing metallic about the light.

And these three requirements are all apart from color, where we should start all over to analyze our lighting in a new way. On this I would say just one thing—avoid saturation as you would poison. Mix in all the white or black you like but never a pure hue.

If we can draw any rule at all from the foregoing, it might be this: The least possible amount of light in conformity with the detail required, diffused and soft, but with a distinct general direction and quietly tinted.

IV.

If you will permit, I will tell you something about one or two interesting opportunities I have had to work out stage lighting problems that presented some difficulties and where facilities were generally lacking.

Many things were learned at the Venetian Fete and Ball given in 1914 by the Society of Ecole des Beaux Arts Architects. This affair was stupendous both in its size and sumptuous beauty. Probably nothing like it has been done since the famous fetes in the Tuilleries Gardens during the 18th Century. The south end of the Hotel Astor ballroom was equipped with a stage 30 feet deep on which was staged the early history of Venice up to the end of the 15th Century, reaching its climax in a spectacle denoting the artistic development of the world to its final blossoming in the Renaissance. There were approximately 250 people in the cast. A relatively large lighting equipment (Fig. 8) was necessary. There were used three batteries of four floods each in the gallery, a flood border and three scenery borders. Color mixers and parabolic strips were used to produce sunset effects on the back drop showing a view over the Grand Canal.

Yet this whole equipment was set up and ready for business in eight hours. Each flood crew had a captain and each captain

and the dimmer operator, who never saw the stage, were connected by telephone with a director who was posted in the upper balcony.

The whole problem was one of painting the spectacle with light; and thereby hangs a tale. The dress and only rehearsal was called in the afternoon of the day on which the affair was given. I had prepared lighting schedules for each battery captain and it was proposed to telephone 'set' numbers as cue. But the floods were manned by stage electricians and after discovering the hopelessness of expecting anything of them I 'fired' the whole lot after the rehearsal, much to the horror of the stage managers (note the plural), and the actual affair was run entirely by telephone with a number of my good friends manning the equipment as volunteer electricians.

It may be of interest to show the form of the lighting schedule as studied from the scenario and action plot. The last few pages and the accompanying scenario plot are produced herewith, the numbers referring to the flood numbers.

It was intended that I should merely telephone the set numbers simultaneously to the captains who would direct their operators, and this was generally done. But, as necessarily the schedule was worked up purely from sketches and the scenario, it could hardly be expected, in a production of such magnitude and complexity, that everything would work out exactly as contemplated, particularly with one very inadequate rehearsal. As a matter of fact many changes were made during the performance as my judgment led him to dictate. That they were successfully carried out was due solely to the intelligence and common sense displayed by the revised crew. It was 'nip and tuck' all the way through, but somehow we managed to pull it off.

VENETIAN FETE—S. B. A. A., 1914.

Spectacle.

Pantaleoni in appropriate verse now craves permission of the Doge to present in honor of the distinguished assembly a Spectacle which interpreted as an Allegory of the Renaissance will be significant of the splendor of the age.

Scenario.

First Movement—The Repression of Sense.—A strain of weird music is heard; the scene is darkened and a girl representing the Incarnation

of the Dark Ages with her attendant Spirits enters upon the stage. In their somber costumes this group personifies the fanaticism and mysticism of the age. As if bereft of sense and subjugated by her sorcery and sinister influence, they follow her in a mad dance wherein in grotesque triumph they proclaim a sovereignty of evil throughout the world.

Second Movement—The Awakening of Sense.—The music changes—one hears faintly the sounds of pipes and bird notes and the rustling of unseen wings. The Spirits of the Dark Ages manifest fear and apprehension of some danger threatening their existence. At once the scene is invaded by a gaily clad company personifying the Five Senses. They engage in a conflict with the terrified Spirits of the Dark Ages and ultimately prevail over them, thus signifying, by the awakening of the Senses, the clearing of the world of violence, superstition, intolerance, persecution and ignorance. In preparation for the Advent of the Renaissance a joyous dance or Bacchanale ensues wherein the Senses celebrate their triumph and prepare to welcome the group composing the third movement of the Allegory.

Third Movement—The Advent of the Renaissance.—In a stately processional a great sphere representing the earth and borne on the shoulders of four men costumed as the Four Races now makes its triumphant entry. Escorted by the seasons and months of the year and a gaily clad group of standard bearers and flower girls, they make their way to the center of the stage. The Seasons carry the several attributes of flowers, corn, grapes, and fagots and with their attendant months execute a stately dance around the sphere. A great chorus of thanksgiving now rises, during which the sphere is illuminated from the interior, faintly at first and increasing in intensity as the music increases in volume. At the culmination of the song the sphere bursts open like the petals of a flower and discloses a girl—the incarnation of the spirit of the Renaissance. Simultaneously, flowers and serpentine are thrown in great profusion from the galleries adjacent to the stage, while the entire scene is illuminated in an immense flood of light. From the earth now in the full flower of the Renaissance, emerge the three great arts of Architecture, Painting, and Sculpture, dominant and resplendent. Three noble figures personifying these arts enter the scene and summon their disciples who rally about their standards. They proclaim their homage to the Doge and present an invitation to the illustrious guests to enter into the joyous diversions of the Ball of the Fine Arts. The Doge now rises, a signal for the procession to form which, led by the student bodies, moves down from the stage into the audience, indicating the conclusion of the pageant and spectacle. (Lighting sets 1 to 9 following.)

Lighting Schedule.

Note: Color filter data given in end of Second Movement.

(Set No. 1) Dimmers: 8th Floor—Transfer connection to white back stage borders to stage plug. Spots: Nos. 9, 10, 11, 12—Unscreen slowly,

focus on aisle carefully, as end of procession passes up aisle all follow until it reaches head of aisle all are focussed on space in front of stage. Nos. 5 and 8—Focus on head of procession as it reaches open space at head of aisle and follow onto stage, then open to flood.

(Set No. 2) Spots: No. 10—Focus on globe as it reaches head of aisle and follow, keep focussed. Nos. 5 and 8—Focus slowly on globe as it reaches head of aisle and follow onto stage, keep focussed.

(Set No. 3) Spots: Nos. 9, 10, 11, 12—Wide flood on stage.

(Set No. 4) Spots: No. 9—Focus on group "Winter." No. 10—Focus on group "Autumn." No. 11—Change to white focus on group "Spring." No. 12—Focus on group "Summer."

(Set No. 5) Dimmers: House—Bring down amber border to out. Bring down blue borders to half. 8th Floor—Bring down back stage strips to half. Spots: All screen slowly to out. (Stage dark.) Nos. 5 and 8—Change to red, keep screened. Nos. 3, 4, 6, 7—Change to amber, keep screened. Nos. 9, 10, 11, 12—Change to white, keep screened.

(Set No. 6) Dimmers: 8th Floor—Bring up stage plug circuit (lights in ball) fast at first, then gradually slower to full in 20 seconds.

(Set No. 7) Dimmers: 3 Plate—Bring up center flood slowly to full on (silhouettes girl in gold).

(Set No. 8) Dimmers: House—Bring up amber borders to full, then bring up white borders to full. 8th Floor—Bring up back stage strips to full. Spots: All unscreen. Nos. 4, 7, 9, 10—Focus on girl in ball.

(Set No. 9) Dimmers: 3 Plate—Slowly bring down center flood to out. Then disconnect "A" and connect "B," 3 color strip. Look out for order of connections; be certain that all plates are at full off. Spots: Nos. 3, 6—Change to blue, focus beam across at high level. Nos. 4, 7—Change to green, focus beams across at middle level. Nos. 5, 8—Focus beams across at lower level. Nos. 11, 12—Change to amber, flood stage. (Note: This arrangement produces a wall of colored light back of girl through which falls silver confetti and streamers.)

(Set No. 10) Dimmers: House—Slowly bring down white borders to out, then slowly bring down amber borders to out. 8th Floor—Slowly bring down back stage strips to half. 3 Plate—Slowly bring up red and green in three color strip. The rest of your operations will be given by telephone. Spots: All flood stage. Then Nos. 9, 10—Slowly screen out, change to amber. After this Nos. 5, 8—Slowly change to green. Then Nos. 4, 7—Slowly change to blue. Then Nos. 11, 12—Slowly screen out, change to amber. Then Nos. 5, 8—Slowly screen to out. Then Nos. 3, 6—Slowly screen to out.

(Set No. 11) Dimmers: 3 Plate—Follow telephone. Spots: All slowly unscreen to half. Nos. 4, 5, 7, 8—Slowly change to green, then to amber, then to white.

(Set No. 12) Dimmers: House—Slowly bring up amber border.

Spots: Nos. 9, 10, 11, 12—Follow procession from stage, focussing on aisle.

(Set No. 13) Dimmers: House on full. Spots: All out, pull plugs.

In November of the same year, the same society gave a series of matineés and soireés artistique at the Ritz, which included the presentation of a pantomine, "The Judgment of Paris," written by Mr. Howard Greenley and staged by Mr. Greenley, Mr. Hewlett and myself. The Ritz having no stage facilities worthy of the name, it was necessary to build a gridiron and proscenium, and stage which included a pool. All of this work was done between Sunday morning and Monday morning. The pool alone entailed the carrying of upwards of 300 buckets of water from the basement.

The pool was the foot-light. It consisted of a curved wooden tub lined with sheet metal and painted inside with Prussian blue. In the pool were gold fish, water lilies, cat-tails and other marsh plants. A motor stirred the surface. The rippling of the stirring device made the sound of a bubbling spring. Reflectors hidden behind a hedge threw light on the pool near to grazing incidence so that it was reflected to the stage. The steps leading from the temple of Minerva to the pool were covered with a mobile pattern of reflections. On the platform before the temple the nymphs danced about the wondering Paris in an interlacing of colored light that caused a constant shifting of hue as they moved. Above stood the towering statute of the goddess before which a brazier burned and gave forth smoke streamers. Behind the goddess a mysterious order of huge columns showed dimly blue in the distance.

The columns were dyed on gauze. Back of the gauze was a light duck drop dyed pale gray blue and on this light played from two parabolic strips set at its base.

The lighting of the stage proper was done by four parabolic floods, one blue on one side and one light amber on the other side, concealed among the flanking cedar trees, and two in the balcony at the north end of the ball room, the latter two being varied in color depending upon the requirements of the action. Thus with pale green and rose color filters in the balcony spots and pale amber and blue from the stage wings, it can be readily seen how

full of color the action must be, particularly with the pale hues of the dancers' draperies to play upon.

Thus four floods at 400 watts each, two parabolic strips at 600 watts each, one parabolic strip as a main border using 600 watts, and a 200-watt strip in the foots—a total of 8 units furnished a simple but effective lighting equipment. The dimmer equipment consisted of three 600-watt plates.

And lastly, it is of interest that the production was very successfully run by a dictograph system, which obviated much of the difficulty encountered with the telephone system used at the Venetian Fete.

A description and lighting lay-out of the "Dispute of the Muses," also staged by Mr. Greenley and myself was given in the *Electrical World* articles.

On February 11 of this year the Society of Beaux Arts Architects will present in the main ballroom of the Hotel Astor an affair to be known as The Ball of the Gods—an artistic embodiment of the mythology of India, Egypt and Greece.

The scene is laid in an abandoned temple on the Island of Cyprus, and requires for its setting a stage the entire length and height of the ballroom, 16 feet deep in front of the boxes on the east wall. A reproduction of Mr. Hewlett's rough sketch for the scenery is given in Fig. 8, to which I have added the first tentative arrangement of the lighting equipment. Unfortunately things of this kind develop so fast that even this sketch was made just in time to get it into this paper.

The sky back is solid gold (color, of course). Oherwise the setting is in black, browns and dark tones, so that the whole effect is that of Chinese lacquer work.

Against this is drawn a rich picture of a pageant of the Gods of Antiquity most sumptuous and color full. There is a prologue, and three episodes, respectively Hindoo, Egyptian, and Grecian, culminating in the birth of Aphrodite or Venus.

And, as in the night of barbarism rose the sun of Greek culture and art, so from the beginning to the end harmonies of light and color play in ever more brilliant crescendo until beauty in its purest form is created amid heavenly glories blinding to the mere human beholder.

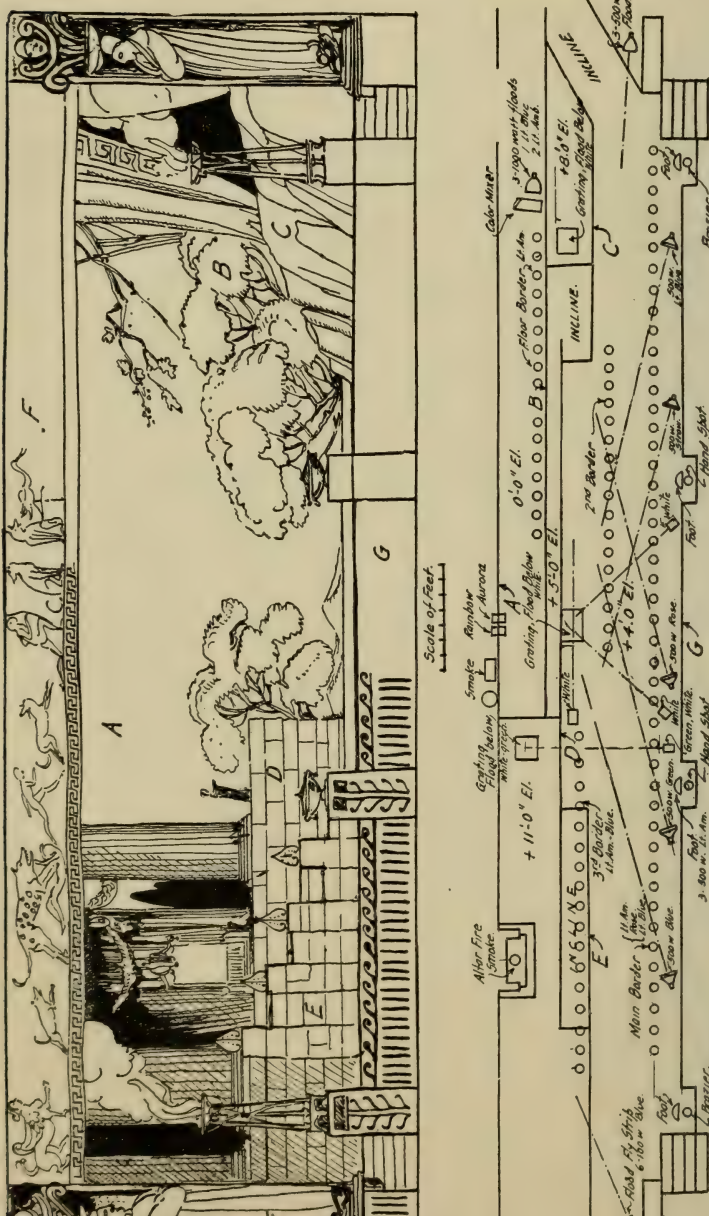


Fig. 8.—The Ball of the Gods, scenery sketch and lighting plan.

At the end of the prologue, three strokes upon the Temple bell and the pageant begins in a pall of darkness in the depths of which is dimly seen the figure of a magician who, with strange gestures, draws forth from his draperies a lamp. Upon being rubbed the lamp glows and emits smoke in ever increasing volume, which, on dispersing, discloses that the magician has changed to Ratri, the goddess of night. She conjures up the spirits of darkness in the form of night moths who dance before her in evolutions just discernible in the waxing moonlight.

Moonlight is best simulated by a light yellowish-green from foots, borders and other sources of general light, with a strictly asymmetric flood of light blue to accent high lights.

But, ere long, the first pale of gray brings upon the scene Ousha, the dawn with her attendant stars, and the rosy mists of the morning.

Remember, the stage is now lighted rather dimly with pale blue-green generally, except the extreme stage right where the temple columns still glimmer a misty deep blue. To this has been gradually added light blue floods, stage left, that give almost silvery high lights to the dancers, the accent being always on Ratri. With the coming of dawn, amber added to the back floods gradually convert blue to white—really gray—which steals out from behind the grove of trees in the back. This is followed by the rosy tints of the early sunrise and, later, by straw-gold.

At the end of the dawn dance enters Vayu the wind god, and his four trumpeters heralding the sun who, in the person of Surya, causes his apish attendants to shackle night with chains in a wierd ballet of struggling forms.

Suddenly a burst of radiance (stage right) shows the high gods assembled on the temple steps whence they evidence their displeasure at the disturbing conflict. And now is declared a festival in their honor, and with the entrance of Rama and Sita and their numerous retinues there follows a series of pictures and ballets typifying the mythological beliefs of ancient India. A fire ballet is danced by Agui, the fire god, and her five fiends in a swirl of flaming color.

Here we do not use anything so crude as color wheels, but a pattern of scarlet, rose, and straw colored lights punctured with

pencils of white through which move the dancers with their flame colored streamers, disturbed by blasts of air through nozzles in the stage floor.

At the close of this ballet night approaches the dancers and again a gloom descends like a pall over the scene. One last despairing burst of flame and darkness discloses the magician returning his lamp to the folds of his dress as he vanishes toward the stage rear.

In this place, this is, perhaps, enough to give you some faint idea of the effects obtained.

Again a slight crescendo of light during the Egyptian period and again dimenuendo to the beginning of the Grecian period, where the rising sun displays his final victory over the spirits of darkness, and light becomes triumphant in the ballet of the spectrum.

But I cannot leave this without telling you something of the finale. And in this I can do no better than give you in full the last of Mr. Greenley's scenario plot of Mr. Lloyd Warren's arrangement of this episode.

Zeus summons Hebe, pledging the assembled gods in the cup of nectar and decrees that henceforth the island shall be dedicated to the worship of beauty and that he will complete the Olympic Circle by the creation of a new goddess who shall be born of air and the cloud mist where the rainbow descends into the foam of the sea.

He directs Apollo to launch a shaft into the clouds while he follows it with a thunder-bolt to summon Iris. The sky instantly darkens and Iris makes her appearance, stage center, followed by her attendants of the prismatic colors.

Here follows the ballet of the spectrum.

At the back, stage center, the light begins to glow and a great cloud of sea mist rises, illuminated by an aurora and tinted with the rainbow.

The light increases in intensity as four nymphs spring into view immediately followed by a shell in which stands Aphrodite clad in misty veils and wearing the Cestus. As the shell rises, the figures of .four Tritons who carry it are gradually disclosed with Posseidon standing in the center. The Tritons hold couch shells to their lips and Posseidon carries his trident.

As Aphrodite rises the attendants of the gods kneel, and the prismatic colors agitate their veils in great billows of color. The whole scene is illuminated to the point of incandescence.

There is a triumphant burst of music and, in the intensity of light and sound, the gods acclaim Aphrodite.

It will be noted that the lighting of the stage is asymmetric throughout; the stage left, from which quarter comes the day, being always the brightest save when the stage center receives the accent during the birth of Venus. The only period of intensity of stage left is during the appearance of the high gods when the raised temple platform receives the accent.

The lighting of the ballets is done from a bridge just back of the proscenium arch on which are mounted a group of parabolic floods with intersecting beams. There are three upper borders unsymmetrically arranged and a set of side floods at each side, those at stage right being of low wattage and always blue, and those at stage left of high wattage, and always amber.

The front of the house lights play an insignificant part in the production.

The foots consist of four units. Each has a diffusing envelope and contains three 500-watt lamps with color filters. In addition a man is located in each of the two center foot shields with hand spots—or light pistols.

There is quite an amount of lighting done from below the stage through gratings, as indicated on the plan.

As all of Mr. Greenley's and my productions have been given for charitable purposes, we were asked last summer to put on a production at the country place of Mr. Charles Goodrich in York Harbor, Maine, for the benefit of the French Orphans' Fund.

A large salt water swimming pool lent itself readily to the requirements and introduced a sheet of water between the audience and the stage which could be made an interesting feature. We decided to build a stage over one end of the pool and stage thereon a pantomime written by Mr. Greenley called "Pierrot and the Rose,—a Night in a Persian Garden." The design for the setting prepared by Mr. Greenley made excellent use of the pool, and used the bath houses and pergola at one end as the basis for the stage structure.

The layout (Fig. 9) and necessary specifications were sent to York Harbor and local carpenters set to work getting out material. The platform, built on stilts resting on the bottom of the

pool, was erected when I arrived on the morning of the day when the performance was given.

I had intended to use 10-cent tinned dippers and dishpans for reflectors where the equipment sent from New York would not meet the situation. But Mr. Goodrich had unearthed a local electrical contractor who had on hand a most surprising stock of steel reflectors and type C lamps. I brought along, two floods,

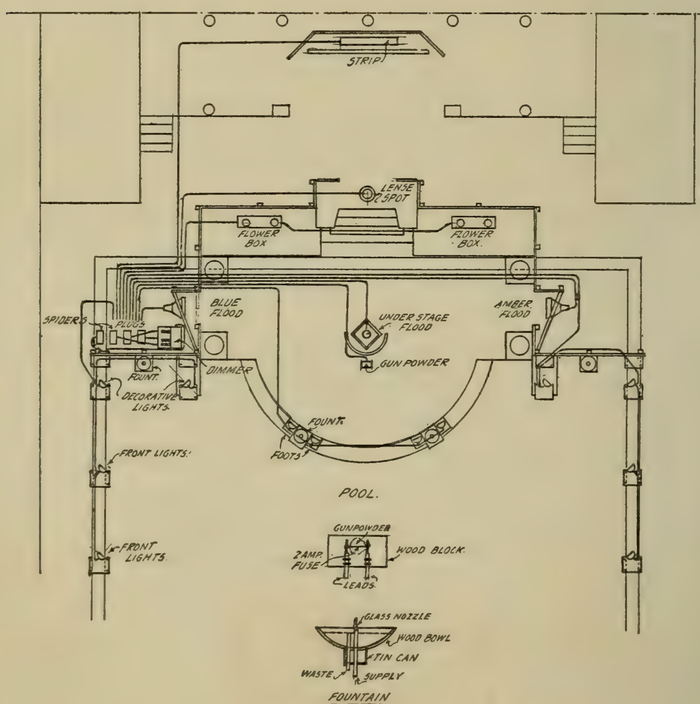


Fig. 9.—"Pierrot and the Rose," plan of setting.

one lens spot and a three-plate dimmer box, while Mr. Greenley took with him lamp dyes and a hundred other necessities.

Men were at once sent out collecting bay and balsam branches and cedar trees. Sod was cut from Mr. Goodrich's lawn to be replaced later. I at once got rid of that bane of all such productions, amateur help, and gardeners, chaffeurs, the farm hands

Fig. 10.—"Pierrot and the Rose," general view.

Fig. 11.—"Pierrot and the Rose." View of stage.

Fig. 12—"Pierrot and the Rose," View from stage.

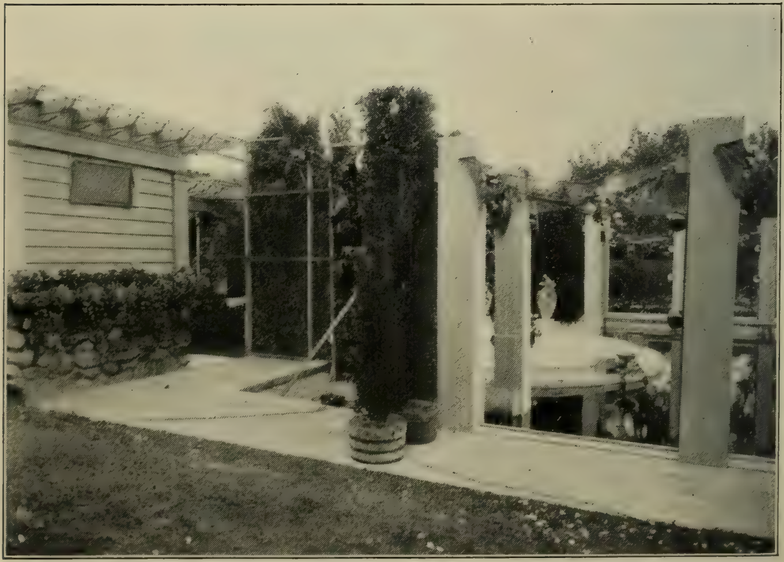


Fig. 13.—"Pierrot and the Rose," Detail.

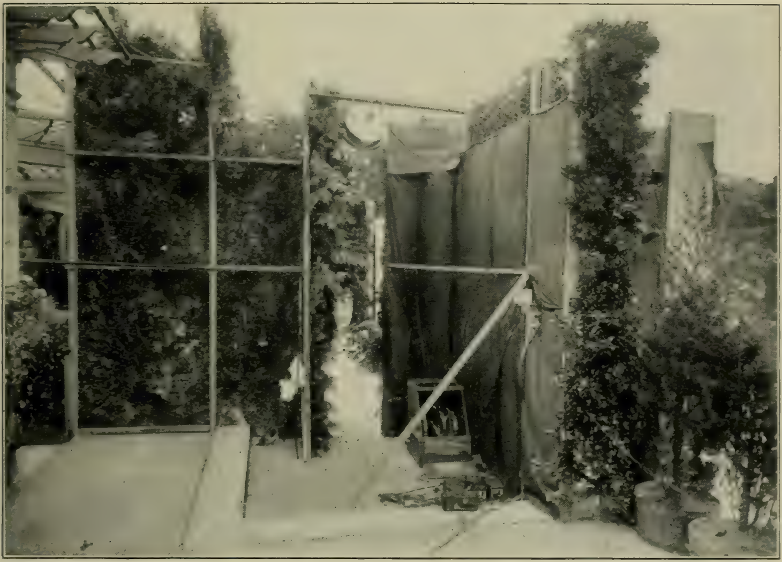


Fig. 14.—"Pierrot and the Rose," Detail.

Fig. 15.—"Pierrot and the Rose." Detail

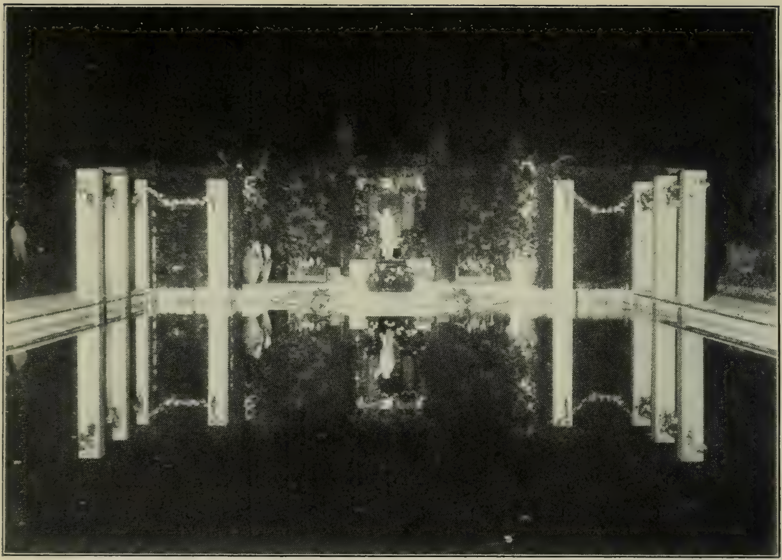


Fig. 16.—"Pierrot and the Rose," Enter Pierrot.

Fig. 17.—"Pierrot and the Rose," Exit Pierrot.

and others, trained to do quickly as they were told, were pressed into service.

Everything lacking was easily procured at the Portsmouth five and ten cent store. The local druggist supplied the necessary fountain nozzles in the form of medicine droppers. Wooden ten cent chopping bowls set on tin cans and gilded formed excellent and effective fountain basins. Dennison's crepe paper pinned to cheese cloth, made an excellent back drop and the wrinkles caused by dampness gave it the appearance of the most sumptuous satin drapery—that is, to the audience at the other end of the pool. A local plumber ran the piping to the fountains and by pounding a section of the lead pipe with a mallet we extemporized a valve to regulate the flow.

The house was stripped of rugs and hangings. Strips of gauze cut from the old gauze drop used in "The Dispute of the Muses" to which were pinned 2-cent paper roses made effective festoons of flowers. A piece of sidewalk vault light borrowed in New York from some kind manufacturer was placed in the center of the stage and under it a dish pan with two 100-watt lamps furnished light for the birth of the rose.

To conceal the vanishing of the rose at the end of her hour's life in human form we ran a duplex conductor under the stage to a point just in front of the rose garden and there fastened the bared ends to a wooden block and connected them with a 2-ampere fuse wire. Over this was poured the explosive contents of a shot-gun cartridge. A plug was driven home on the other end of the line and—whif!—a fine smoke cloud behind which the rose might sink back to her bed.

Meanwhile the wings and backs of two by fours, lathing strips and chicken wire thatched with branches now coming by the cart load, grew apace. And presto! the transformation was complete and dress rehearsal began on time.

The lighting arrangements consisted primarily of two 500-watt floods, one stage right and one stage left, amber and blue. Each foot group at the fountains consisted of two 100-watt lamps in white enamel reflectors, amber and blue.

Having no borders or front of the house lights save the full moon, the tines, or upright posts of cheesecloth and lathing strips

placed on each side of the pool served not only their purpose as decorations but also to conceal light sources of 100-watt lamps in white enamel steel reflectors. A single 500-watt lense spot among the foliage over the steps to the door stage rear, served to bring out into brilliancy the calif and his executioner. A single 600-watt parabolic strip lighted the crepe paper back drop. Nothing coud be simpler or more effective.

One last feature was the dying of the water in the pool with malachite green to enhance its effect as a mirror.

V.

And now, if, by these few examples, I have given you any insight into the possibilities of stage lighting, I shall have done more than I can hope. The subject is so vast, so interesting and so dependent upon a multitude of governing conditions that no rules or principles apply. One might quite as well attempt to tell you something of the possibilities of painting, for feeling rather than logic or reason must govern the procedure. There is no necessary complication in the apparatus; the art is in handling it.

APPENDIX.

Notes on Stage Setting and the Relation of the Action to the Scene, by Howard Greenley.

It may be said that there are three systems in existence, all of which are to a certain extent prejudicial to the actor.

The old style with the usual back-drop treated as a receding painted perspective was so artificial in character that the actor was obliged to force himself in front of the scenery by a deliberate, artifical, theatric style of acting.

The school of stage setting as exemplified by Gordon Craig, Barker, and others, wherein the background and other scenic accessories have relatively nothing to do with the actor or action. There is no relation between them. They impose upon the play an atmosphere wholly foreign to it (as for instance Shakespeare staged with a German Persian flavor). An effect of this kind conveys an atmosphere localized and which by reason of its obvious falsity leaves the audience in a state of bewilderment and unable to apprehend either the intention of the play or of the stage setting.

The Urban type of stage setting completely obliterates the actor by reason of its extraordinary brilliance and sumptuousness and by the "bizarre" quality of design. The eye of the audience is so attracted to

the stage setting as to render the actor entirely unessential to the picture, as for example, "In the Garden of Paradise."

In order that the actor and the stage may exist in entire consonance it is suggested that the setting may possess atmosphere without locality, such as plain backgrounds, or drapings in color, which is a perfectly reasonable solution, and at the same time obtain a desirable quality in a scene. Or, if a locality is specified, that it shall not be foreign to the intent of the playwright's conception. There is no intention to object to the use of dramatic effects or exaggerations of color and form in the scenery, the only requirements being that the scene itself shall be actual, natural and recognizable to the audience. The action then would more naturally fit into the stage setting forming a perfect co-relation therewith. The color and design of costumes should by the same token harmonize with the scene, in order that the effect of color harmony may be secured as suggested above. This is one of the chief objections to Bakst; a master of color and line in his costumes. He, nevertheless, at times sacrifices what he achieves in this respect by a background that is confused and broken, and does not permit the full value of his costumes to be realized.

It is almost axiomatic that the value of the optical appeals to the greater number of people. In this theory of production action and musical accompaniment should be in consonance with the project but subordinated at all times to the optical. The illusion primarily is perpetually attractive and hence the success of plays or other productions which have been based on legends, folk lore, and fairy tales. All of these sources of theatrical inspiration possess this desirable quality.

DISCUSSION.

Mr. M. Luckiesh: We are all appreciative of Mr. Jones' work along the lines discussed by him in this interesting paper. I am sorry that he did not touch more upon the modern theatre as exemplified abroad especially, by such men as Gordon Craig and Max Reinhardt. In stage lighting as in any other lighting field we must deal with light, shade and color; however on the stage we have wonderful opportunities for studying and applying the effects of light, shade, and color excelled in no other fields. I support Mr. Jones' criticism of the crude realism of the average stage although realism has its definite place and is essential in its right place. Stage lighting has a great future but I believe experiments should follow the lines of the 'language' or the 'emotive value' of light, shade, and color. I am particularly interested in the new movement in the theatre which, like most radical departures from the conventional rut, has done considerable good

if it has no more than pointed out the mistakes in the setting and lighting of the present stage or in the presentation of the drama. It is difficult to give an idea of this new movement in a few words. However, there are various excellent books upon the subject which are available in public libraries.

No play is properly presented unless the play, the setting, and the lighting harmoniously combine in their individual results. The modern theatre utilizes light, shade, and color in lighting and setting to produce the proper spirit or atmosphere. Instead of having the old deserted mill (poorly imitated) as the scene for a murder, the modern stage-artist attempts something far more commendable than realism, namely the creation of the proper atmosphere or spirit by lighting and by simple settings. Perhaps the new movement will not reach any relatively greater percentage of people than the modern symphony in music. Nevertheless it is an interesting and beneficial experiment in the presentation of the drama.

A few years ago the stage setting consisted chiefly of flats upon which many details were painted. The fireplace was painted on the flat and numerous articles were painted 'upon' it. The shadows were unreal and inconsistent with the real shadows in general and the perspective could never be generally satisfactory. Next came the realistic setting which had the advantage of consistent and real shadows. The new movement, in one aspect, tends toward the elimination of every unnecessary article from the setting and the few shadows which exist are *real*.

This brings us to the point of considering the shadows on the stage. The foot-lights are in a wrong position to produce generally pleasing and natural effects. The features of the actors faces are usually grotesque in appearance. Surely a determined effort should be made to eliminate the foot-lights or to modify them. This is a difficult task but I believe the combined resources of the architect and of the lighting expert can do a great deal toward correcting this condition. A great deal more could be said in discussing the possibilities. However, I believe the important step is toward ascertaining and utilizing the 'language' of light, shade, and color.

ILLUMINATION IN THE NAVY.

BY LIEUT. C. S. MCDOWELL, U. S. N.

Synopsis: This paper briefly covers the use of incandescent and arc lamps for general illumination on shipboard, for searchlights and for signalling purposes. The design of reflectors, size of carbons and color of light are given as important features in searchlight efficiency. The use of searchlights, illuminated semaphores, and blinker lights are considered from the standpoint of visibility for day and night signalling. The appendix is a tabulation of intensities of illumination which should be obtained in the various compartments of the ship.

The general art of illumination in the navy has followed the various developments and progress of illumination on shore. The conditions existing on board ship however are so different from the usual conditions on shore that special apparatus is required in most cases. Although a naval vessel is purely military, and therefore all means of illumination on such a vessel may be termed military, the various means of illumination may be divided in the following classes, some of which are purely military and others not: illumination of spaces on shipboard; illumination of distant objects by projected light from searchlights; signalling by means of light; special illumination, such as gun sights, compass cards, etc.

ILLUMINATION OF SPACES ON SHIPBOARD.

This includes the lighting of officers and crews living spaces, machinery spaces, firerooms, turrets and gun compartments, shell rooms, powder magazines, sick bays, coal bunkers, upper deck spaces, gangways, etc. The requirements on naval vessels where the numerous compartments have low head room and are assigned for special uses (in some cases two or three uses) ; liability of damage due to shock from gun fire, and the necessity to maintain the integrity of the water-tight compartments; all make it necessary to provide special types of fixtures, and methods of installation. In 1912 the Navy Department started a special investigation on this subject which lead to the adoption of an

*A paper read at a meeting of the New York Section of the Illuminating Engineering Society, October 14, 1915.

ideal table of intensities of illumination which should be obtained in the various compartments and spaces. This table is given as an appendix. It has of course been necessary to vary from this table to a certain extent, but a great improvement has been made in illumination of spaces on shipboard, especially on new ships which have been built since this investigation was made. Standard types of fixtures, globes, and shades have been developed to get the desired results. On account of the low ceilings and white wall surfaces the fixtures are mostly of the indirect or semi-indirect type. Incandescent lamps are used entirely in the newer installations; tungsten lamps of 25, 40, 60 and 250 watts are installed in most places except for portables, where, on an account of breakage, carbon lamps are used. The 250-watt units are installed in the engine rooms, fire rooms, dynamo rooms, etc., where high head room is available. The standard voltage until the last two years has been 125. On the newer battleships 240-volt generators are installed with a three wire system to the distribution boards. The lighting circuits from the distribution boards are 120 volts.

On board battleships there are two regular lighting circuits known as, *battle* and *lighting*. The battle circuit includes all circuits below the protective deck, circuits to guns, searchlights, signalling apparatus, running lights and in general all the lights which would be absolutely necessary in action. The *lighting* circuit includes those which may be dispensed with in action.

In addition to the above there is installed an auxiliary (or emergency) lighting circuit which is of 20 volts, supplied by storage batteries, with the minimum number of lights installed at the various necessary locations, this circuit is automatically energized when the main circuit breakers on the regular lighting circuits pull out.

SEARCHLIGHTS.

Searchlights are principally installed for military purposes but in addition are necessary on any ship for navigational purposes and are found useful for general illumination when coaling ship, taking on stores, etc.

There are a number of different military uses of searchlights, such as illuminating an enemy vessel or aerocraft so that the guns may be properly aimed at the target, illuminating of shore forti-

fications for the same purpose, searching of shore for enemies forces as a means of protection of landing parties, etc.

For navigational purposes they are used for picking up buoys and navigational marks, in coasting and entering harbors, and for illuminating docks when berthing at night and for navigation in a fog.

Searchlights have been in use for about fifty years. Until the last couple of years their development has been practically stationary for about twenty-five years. The great increase in range and reliability of the modern torpedo increased the demand for greater range for the searchlight. As the searchlight is a defensive weapon against night torpedo attack, different engineers and scientists in the various countries have been and are working on this problem. The development has of course been greatly accelerated by the present war, for the searchlight in various forms and sizes is used on land for as important military purposes as at sea.

Although a number of others have made certain advancements lately in searchlights it is believed that the principal credit for the modern searchlight, which in some form has been adopted during the past year by most countries, is due to Mr. Henrick Beck of Germany.

The searchlight considered solely from an illuminating standpoint consists of a source of light and a reflecting mirror. The most efficient reflecting surface is a glass mirror with silver surface and the best source of light is the carbon arc. The military purpose of the searchlight is to throw as intense a beam of light as possible on the target and therefore the angle of dispersion of the projected beam should be a minimum so as to decrease the zone of light and increase the zonal candlepower. To accomplish this the mirror is made in a true parabolic form, the source of light is made a minimum and the focal length made a maximum, consistent with obtaining the greater part of the light, given off by the source, on the mirror. On shipboard the size of the mirror and searchlight drum, is restricted by the necessity that it must not be too cumbersome for handling in a rough sea and in the space available. The focal length depends upon the diameter of the mirror. Therefore, to decrease the angle of dis-

persion and increase the illumination on the target it becomes necessary to decrease the diameter of the source of light without decreasing the candlepower. In the latest searchlights the diameter of the positive carbon has been decreased to one half the diameter formerly used, although the amperage has been increased so that with a crater of ⅝ in. (15.87 mm.) diameter there is obtained a maximum luminous intensity of 90,000 candlepower and a zonal candlepower throughout 70° of very near that amount.

The 36-in. (0.91 m.) diameter mirror is the standard for large ship installations in this country, in the new type of searchlight the maximum candlepower of the arc has been increased from about 50,000 to 90,000 and the area of the beam reduced to one fourth that formerly obtained so that the illumination received on the target is more than six times as great as that from the older type. This has been accomplished principally by putting 150 amperes through a positive carbon only ⅝ in. (15.87 mm.) in diameter and providing means for carrying off the heat. The composition of the positive electrode is very important. It contains a fairly large core of white flaming material. The negative carbon is set at an angle to the positive, as is frequent practise in projector lamps, so that the negative flame impinges on the positive in such a manner to hold the luminous flame confined within the positive crater. This effect seems to require a certain minimum current which is approximately 90 amperes. If the current goes below this amount the velocity of the negative flame is reduced to such an extent as to allow the positive stream to emerge from the crater and intermingle with the negative flame; whereupon the arc takes on the characteristics of the ordinary flaming arc.

The size of the negative carbon has also been reduced so that it is now for 150 amperes but $^7/_{16}$ in. (11 mm.) in diameter compared with 1 in. in the older type. This reduction in size of the negative carbon had been made by others, however, before Mr. Beck's lamp was produced. The advantages of the small negative electrode are that the shadow cast on the mirror is reduced, which feature is especially important from the fact that the candlepower of the arc crater increases as the angle from the nor-

mal decreases. The centralizing of the arc by means of the small negative keeps the light much steadier and at the focus of the mirror. The positive carbon is rotated to increase the steadiness of the arc and to keep the crater edges even. In the Beck lamp this rotation also provides for the bathing of the carbon in an indifferent gas to prevent oxidation and increase the cooling of the carbon shell.

Some tests have been carried out by the navy and by others on nitrogen-filled tungsten lamps as a source of light for searchlights. It is evident, however, that these lamps can not compare in intrinsic brilliancy with the carbon arc, although they contain the desirable features of fixed position of source of light and steadiness, and without the necessity of loss of power in stabilizing rheostats. The concentrated tungsten-filament searchlight will probably be developed so as to be satisfactory for such searchlights as are required for navigational purposes where it is not necessary to illuminate objects at great distances.

The question of the color of the projected light is interesting for a number of reasons. In the new highly luminous arc the light given out contains a large percentage of blue and violet rays, and as the ordinary highly efficient silvered mirror reflects most of the light, the color of the beam also contains a great percentage of blue and violet rays. The light received by the eye is that reflected from the distant object, if the observer is stationed clear of the stray light from the beam, and therefore very dim illumination is obtained. Under such conditions the maximum physiological effect has shifted from the yellow toward the blue end of the spectrum and, as the object illuminated is likely to be of a bluish gray color, the ideal condition would seem to exist. The varying condition of the atmosphere may, however, cause a decrease in the intensity of illumination by at least 50 per cent. due to absorption and refraction of the light rays in the beam; the shorter wave-lengths are much more affected than the longer ones. This same proposition in an exaggerated condition exists in a fog. In some experiments conducted in artificial fog, it was found that when using silvered glass mirrors the illumination of an object 40 ft. (12.19 m.) distant from the light through the fog was but 21 per cent. of the illumination under normal conditions;

on the other hand using a gold plated glass mirror the illumination under the same conditions was 60 per cent. of that obtained under normal conditions.

As the human eye is not achromatic, the advantage of using monochromatic light in searchlights is evident. The acuity of the eye is also greater for certain monochromatic rays than others and it is known that the visual acuity of the eye for equal intensities of light is greater for yellow light than for that of any other color. Thus, although the gold backed mirror does not reflect only one color, the fact that it reflects a beam containing a greater proportion of yellow rays than the beam reflected by a silver backed mirror makes the distant objects illuminated stand out in greater detail. This fact has been observed in various tests. Possessing as it does certain advantages, the gold backed mirror has been extensively used by certain countries; but it would seem that for normal conditions it would not be advisable to use it with the later type of arc light which gives off a light strong in blue and violet rays.

The modern searchlight is trained and elevated from a distance by either mechanical or electrical control apparatus so that the person controlling the movement of the light may observe the target without being blinded by the glare of the stray and refracted light. Searchlights are usually fitted with a shutter so that the light may be kept burning ready for use but darkened until such time as it is desired to illuminate the target. The name searchlight is somewhat a misnomer in a military sense, for a searchlight is not as a rule used for searching, but principally for illuminating the target after it has been discovered by pickets or other means. The use of a searchlight in the first instance betrays the position of the ship using it to the enemy before the enemy itself can be discerned.

Metal mirrors of various compositions and colors have been used to a certain extent, principally to prevent breakage due to the shock of gun fire. They have, however, been found to have a low coefficient of reflection and to tarnish very quickly. They require much care to keep properly polished and they are not made as true to parabolic form as is the glass mirror. On land they have the further advantage that they can stand rifle fire without serious damage to their usefulness.

SIGNALLING BY MEANS OF LIGHT.

This subject may be divided into two general classes: interior communication signalling on board ship, and distant signalling.

Interior communication light signals comprise numerous different circuits and systems for giving definite and fixed indications or messages, by illuminating a glass or other translucent dial which contains the message or indication, and thus being similar to many uses of light signals on land.

Distant signalling consists principally of the following systems: Ardois; night semaphore; blinker light; searchlight.

The ardois consists of four lamps mounted in a vertical line, one above the other, as high up as possible in the rigging. Each lamp is double containing a red and a white light, and these lights are controlled from a keyboard arranged similar to that of a typewriter. The continental Morse code is used. A red light indicates a dot and a white one a dash. This gives a very simple signal system as the keys are lettered and numbered so that any one may transmit a signal with it. This system, however, can not be used for any considerable distances and it is comparatively slow in operation. Moreover it is available only at night and is used mostly for tactical signals.

The semaphor system of signals consists of a different position of the arms for each letter and numeral, a sort of alphabetical calesthenics. It was originally used by the British and the French for signalling with a flag in each hand; later it was adopted by this country. While it has been used to a certain extent with hand flags, a machine has been developed containing two swinging arms which were made about 6 ft. (1.7 m.) long and could be seen distinctly at much greater distances than the flags. Furthermore these swinging arms are equipped with tungsten lamps and a reflector so that they may be used at night.

The blinker signal system consists of a pulsating single light or one which may be mechanically oculated. It is controlled by a telegraph key and the continental Morse code is used. Rapid signalling may be affected by its use, but it is available only for night work.

The use of the searchlight for signalling gives a visual means of signalling at great distances. Signals have been sent by this

means at least 50 miles and before the advent of radio telegraphy this promised important developments. The introduction of radio apparatus on board ships obscured the real field of searchlight signalling for a number of years and it is only lately that it has again been taken up.

In the present system of searchlight signalling the Morse code is used and the emission of light controlled generally by a quick acting shutter, either hand operated or electrically operated by hand key and relay control. There has been developed more recently, however, a system of controlling the light itself by means of a telegraph key without requiring the mechanical striking of the arc. A number of different means have been developed for accomplishing this. By striking the arc with high frequency high voltage, the arc once struck may be maintained by low voltage. By shunting the arc with a resistance, the current in the main line may be maintained constant and the current across the arc reduced to about one tenth of its normal value, the variation in light given out producing the same effect as if the light was actually shut off.

The searchlight can be used equally well in the daytime and is generally so used, acting in this case as a heliograph. It possesses the additional advantage in daytime of selectiveness in that ships at a few degrees from the object on which it is trained can not see the flashes. In daytime small searchlights have been used successfully for over-eight miles. For long distance night work the searchlight is trained on some dark cloud in the general direction of the receiving ship.

There are a number of special uses of illumination on shipboard. Among such special uses is the illumination of the compass cards. With the use of a dimmer the markings of the compass are distinct but no glare is produced to dazzle the eyes of the man at the wheel. The illumination of the cross wires of the telescopic gun sights is another example.

APPENDIX.

Foot-candle Intensities.

Ammunition passages	2.0
Armory, plus metal reflectors at bench	2.0
Battle dressing station	2.0
Battle dressing stores	2.0
Bakery	2.0
Bath room	2.0
Barber shop	2.5
Boiler rooms, plus 250-watt units	1.5
Butcher shop	1.5
Band room	1.0
Blower room (special)	—
Blower space	1.0
Cabins	3.0
Carpenter shop	3.0
Chart house	5.0
Chief P. O. quarters (berthing)	1.5
Chief P. O. quarters (messing)	2.0
Crew's space	1.5
Country (officers')	1.5
Crew's wash room	2.0
Crew's water closets	2.0
Conning tower (special)	—
Chain locker	1.5
Coal bunkers	0.7
Coaling ship (special)	—
Dispensary	3.0
Desk	4.0
Distribution room	2.0
Dynamo room, plus 250-watt units	1.5
Decks, outside (special)	—
Engine room, plus 250-watt units (treated special)	1.5
Evaporator room	1.5
Firemen's wash room	2.0
Foundry	3.0
Fire room (treated special)	—
Fuel oil relay tank room	2.0
General condiment and issuing room	2.0
General mess pantry	2.0
Galleys	2.0
Handling room	2.5
Interior com. room	2.0
Ice machine room	2.0
Isolation room	2.0
Issuing and store room	2.0
Laundry	1.5
Lamp room	1.5
Machine shop (general)	1.0
Magazine	1.5
Mess rooms (officers')	2.5
Mess attendants' wash room	2.0
Offices	4.0
Operating table	15.0 to 25.0
Paint room	1.5
Paint mixing room	1.5
Pantries	2.0
Printing office	4.0
Pump room	1.5
Post office	4.0
Prison (special)	—
Reception room	3.0
Surgeon's examining room	2.0
State rooms	3.0
Sub	4.0
Sub central	4.0
Shell room	2.0
Store rooms (fixed stores)	0.7
Store room (stock for issue)	1.0
Sick bay	2.0
Storage battery chg. sta.	2.0
Ship's store	2.0
Torpedo room	2.0
Turrets (special)	—
Water closets	1.0
Wireless room	3.5
Workshop (additional special illumination to be provided at machines)	1.5
Windlass space	1.5

DISCUSSION.

Mr. D. M. Mahood: I have prepared a few notes on Lieut. McDowell's paper that pertain particularly to the searchlight sections. A comparison of the card candlepower distribution curves of foreign made carbons, with those of American made carbons, in our lamps, shows a considerably broader peak of maximum intensity and a remarkable saving of candlepower at its normal behind the negative. This is a very important factor. We are now making up these lamps for various branches of the service.

Mr. J. L. Minick: Steam railroads have a problem which, to some extent, approaches that of the searchlight; that of providing at the head end of a train a light giving a beam of approximately parallel rays. This light serves four principal purposes: It serves as a marker to designate the head end of a train; it serves to warn the public of the approach of a train; it serves as a means of illuminating the number of the locomotive which is used in recording the movement of the train and finally; it serves to illuminate the track immediately in front of the locomotive.

In fixing the intensity of the beam from this light other features must be kept in mind. The entire absence of light at the head end of the train is the most desirable condition for the correct reading of colored signals by which the movements of the train are guided. Daylight or as much light as it is possible to secure is the most desirable condition for illuminating the track ahead of the locomotive. It is obvious that the value selected must lay between these two extremes. It is also necessary to give some consideration to the angular spread of the beam and the color of the light.

The principal difficulty encountered in the endeavor to solve this problem has been the woeful lack of definite information as to what can and what cannot be done with the several sources of light and reflectors or other devices designed to give a beam of approximately parallel rays of light. It has been necessary to conduct many tests and the data secured has not always been consistent. Much of this data has been given to this Society. At the Washington Convention a most excellent paper was read on this subject. So far the railroads have been endeavoring to collect

and analyze all of the data bearing upon their particular problems. I do not know how much information is available concerning searchlights but I do know that those of us who are endeavoring to solve this railroad problem, have been able to secure only a small amount. I cannot help but feel that more data of this nature will be o fus and value to both the army and navy and the railroads generally.

Mr. Sperry: With reference to arc lighting, I would say that in 1879 I started by making an arc lamp, and I also made at that time a dynamo and an automatic regulator, so I could turn on and off, lamps run in series. Next I made a ten light machine and a twenty light machine, which I took to Chicago. On my twenty-first birthday I opened a shop in which I built this equipment. In three years we had a great many arc lamps all through and off, lamps run in series. Next I made a ten light machine always have been interested in keeping up with the advances on both sides of the water.

A year ago I was in Berlin and met a friend who had been observing a powerful arc lamp made in Germany. I had been working along with "effect" carbons and it was very gratifying for me to find that these people were working along quite different lines. Our work has progressed under the able assistance of some of my aids here and we have produced a result that I am sure will be useful. The beam seems to be somewhat more intense and uniform than the light referred to. We have also striven toward quite a number of structural features, as you see the arrangement before us with the center pole and the guyes on the sides gives considerably less shadow. Another thing that we have really accomplished is to simplify to a great degree the operation of the lamp, doing away with any supply of gas, alcohol, or other fuel, and also to get the negative holder down so that it gives absolutely the minimum of shadow. Of course whatever holder you supply stands between the arc and the mirror. This general form of lamp has been operated for many months. Of course at first we had to make changes. Later we have had to change the manufacturing of the carbons and finally their adjustment to the proper current. All of this work has been intensely interesting to me, and if, as I have said, it shall

be found to have produced a useful result, I shall certainly be gratified.

Dr. C. P. Steinmetz: I would like to ask Mr. Sperry a question regarding his very interesting flaming searchlight. How does the minimum dispersion angle of the complete searchlight compare with that of the Beck light? The candlepower curve of the arc lamp proper does not yet determine the efficiency of the searchlight using it. There are two problems—the first one is to get as large a light flux as possible, and the second, to concentrate the light flux into a minimum angle so that it carries the beam as far as possible. The flame lamp has been with us for quite a number of years and we know that it gives much more light than the old carbon arc, but previous attempts of utilizing it for searchlights have failed because the light comes from the flame, which has a lower brilliancy and a larger area than the incandescent crater of the carbon. The minimum dispersion angle of the searchlight cannot be less than the angle subtended from the center of the reflector by the luminous source, and what I consider as the main feature of Beck's work was to concentrate the area of the luminous source by having the flame concentrated in the interior of the carbon by cooling its outside and by having the flame in the contracted space, so practically run a superheated flame arc. This gives us an excessive brilliancy of the luminous source in a very small area and thereby an extremely small dispersion angle, that is, a high efficiency of the searchlight beam. I would like to ask, how in your searchlight the dispersion angle compares with that of the Beck light, and how much of the light flux of the source comes in this angle.

Mr. Sperry: I think Mr. Bassett Jones possibly could answer that. He has been working now for a great many months on just that point.

Mr. Bassett Jones: I would say on that point, that our carbons are the same size that are used in the Beck lamp but on account of the lack of the inert gas there is a very slight tapering which allows our crater to measure perhaps a millimeter less than that which Mr. Beck's crater would measure in his lamp and that although we get the same candlepower, or more, than has been gotten in the Beck type of lamp, we are getting it from a smaller

source. And more than this, the smaller source will give a smaller angle of the dispersion of the beam.

MR. L. C. PORTER: There are a few points I have noticed in the paper particularly in regard to the penetration of the fog by using gold backed mirrors. There are two factors that enter in there; one is the ability to pick up objects at a distance, which is primarily the one in which the army and navy are concerned; the other, as Mr. Minnick has brought out, is the ability to read signals when looking toward a powerful searchlight.

The tests which I have made and which I have seen, seem to indicate that by the use of amber front glass over a headlight or searchlight you can pick up signals a little closer to the searchlight than where the clear light is used; that is, the glare is reduced somewhat. But I have never yet been able to pick up objects at any greater distance with an amber beam than with a clear beam, provided the two beams were of equal intensity.

I notice in the ardois signal set and in the blinker set that the lamps which are used do not have particularly concentrated filaments. These are lens lanterns and by using a concentrated light source, such as the focus-type high efficiency incandescent lamp, you can considerably increase the range of the signal without increasing the wattage.

In regard to the incandescent searchlight and the arc searchlight, there are a few fundamental differences which I would like to point out. Taking the light sources themselves—with the arc most of the light goes from the crater in a fairly narrow angle of distribution, and naturally the crater pointed toward the mirror reflects it out. There we have a shadow of the carbon in the beam. On the other hand, when you use the incandescent lamp you do not have this shadow, but you have one drawback—which is the fact that the light source is not a solid source. Using the incandescent lamp, of course, we do not have the gas vapors to contend with, and as the distribution from the focus-type lamp is pretty nearly spherical, it is necessary to use a mirror for very short focal lengths, to utilize a high percentage of the available light flux. You will notice these searchlights here are made with metal mirrors of very short focal lengths, so that they include a very high solid angle.

The resulting beam depends a good deal on the size of the light source in incandescent sources, as well as arcs, and for that reason where you wish a very powerful beam, it is necessary to use a highly concentrated incandescent filament. To get the high concentration we have to go to low voltage. An interesting test was made with a 20-in. (50.8 cm.) searchlight equipped with a 6-volt 108-watt lamp, which has its filament coiled up into a single helix 2 mm. in diameter and 6½ mm. long. This combination gave very nearly as high a beam candlepower as a 750-watt 30-volt lamp; in fact, 6-volt lamps have been made, which, when used with 13 in. (33 cm.) mirrors gave as high as 700,000 beam candlepower.

There are several different types of incandescent searchlights on the market. Those known as flood lighting projectors are good lighting units, which should be of considerable service in navy work, around docks and piers for loading and particularly for coaling ships where they have to take the coal up from out of the barge and carry it across the deck and drop it down a manhole. Such units will give a spread-light. Their beams can be spread out to about eighteen degrees, effective up to several hundred feet, or concentrated to six degrees, for longer distance work. There are a good many other fields for the smaller sized searchlight, which can be taken care of with such units.

There are available different focus-type incandescent lamps, for searchlight purposes, ranging anywhere from 1 candlepower up to 5,000 candlepower. Dry batteries are being used considerably for searchlight work too. There is a unit on the market now with a single dry battery cell and one lamp which will throw a beam, effective up to 200 or 350 ft. (167 to 250 m.). The European armies are using large numbers of these.

Mr. Day: I want to ask one question about the test that was shown on the screen. Of course some of the light comes from the flame in both types of searchlights that have been mentioned, and in ordinary tests that flame light also appears as producing parts of the candlepower shown. But, of course, only the crater is useful in forming the searchlight beam because the rest of the light, the flame light, is not into the focus.

MR. BECK: I have always understood that the crater of a hard carbon arc was either a cone, the interior of which was bright, or a nearly flat surface, and that the crater of this flame arc is the interior of a very deep cone, which, of course, would be a very narrow length. It seems to me that the efficiency in the flame carbon depends on this.

MR. SPERRY: If there is a little tongue of the flame protruding, a very large per cent. of the light emanates from the crater contents. But you are absolutely wrong in thinking that the light emanates from the crater surface. The light emanates from the flame within the crater. Our purpose is to keep this vapor confined to the crater and not allow any large part of it to come out, and in so doing, keep it confined to the smallest possible light source. Now the two curves were taken under identically the same conditions for the Beck arc and for this. Our crater for the same current is somewhat smaller and the light source of the beam of the other lamp proves to be about 30 per cent. greater in area.

TRANSACTIONS

OF THE

Illuminating Engineering Society

NO. 5, 1916

PART II

Miscellaneous Notes

Council Notes.

A meeting of the Council was held June 8, 1916, in the general offices of the Illuminating Engineering Society, 29 West 39th St., New York, N. Y. Those present were: Chas. O. Bond, H. Calvert, Wm. A. Durgin, C. A. B. Halvorson, Geo. A. Hoadley, Clarence L. Law, C. A. Littlefield, general secretary; Preston S. Millar, A. S. McAllister. Upon invitation: C. E. Clewell and Geo. H. Stickney.

By reason of the absence of the President, Dr. Charles P. Steinmetz, Mr. Geo. A. Hoadley, vice-president, called the meeting to order at 2.30 p. m.

The minutes of the May meeting were adopted as printed.

The Finance Committee presented a report recommending the payment of vouchers Nos. 2526 to 2555 totaling $1,291.25, which includes the payment of $143.00 for TRANSACTIONS in excess of the amount allowed in the budget. This report was accepted and the above-mentioned vouchers authorized paid, including the $143.00 for TRANSACTIONS expense in excess of the appropriation.

After considerable discussion on this question of finances, it was moved and carried that in order to meet this deficit the officers of the society be instructed to sell one of the bonds belonging to the society on the most advantageous terms, as early as possible, and, should they consider it necessary, the second bond should be disposed of.

After a report was presented by Dr. A. S. McAllister as chairman of the special committee for limiting the TRANSACTIONS expense, the chairman of the present Finance Committee was requested to formulate their ideas of financial procedure for the benefit of the succeeding Finance Committee.

Upon recommendation of the Board of Examiners the following applicants were elected:

To the grade of member, 4.

To the grade of associate member, 15.

Transfer to the grade of member, 1.

The resignation of one member was accepted with the usual provision that he be informally reinstated should his resignation be withdrawn before the end of the fiscal year.

A report from the Committee of Election Tellers was accepted and it was moved that an official notification of election be sent to the officers-elect.

Progress reports were received from the following committees: (written) 1916 Convention Committee; (oral) Committee on Papers, Administrative Committee on Lectures, Membership Committee. A report from the Exhibition Booth Committee (Electric) gave a summary of the financial condition of this committee.

Oral reports on section activities were made by Mr. C. L. Law, vice-president representing the New York Section; Mr. C. A. B. Halvorson, vice-president representing the New England Section; Mr. Geo. A. Hoadley, vice-president representing the Philadelphia Section; and Mr. Wm. A. Durgin, representing the Chicago Section.

It was moved and carried that those men who are now delinquent be dropped as in accordance with the constitutional requirements.

It was decided that the annual report of the society to the membership be prepared by the general secretary and submitted to the Council before the annual meeting in October.

The following committee was appointed to draw up a resolution to be presented to Mr. Joseph Langan expressing the appreciation and thanks of the society for his faithful and efficient

work while with the society: Preston S. Millar, chairman; C. O. Bond and C. L. Law.

Section Meetings.

CHICAGO SECTION

June 29, 1916, Edison Building, 125 South Clark Street, Chicago, Ill. Subject: "New Developments in Reflectors and Shades for Gas and Electric Lighting." The manufacturers of glass and steel reflectors and shades were invited to present, in ten-minute talks, the newest developments in their respective lines. Supper was served at the Chicago Engineers' Club preceding the meeting.

NEW YORK SECTION

June 8, 1916, United Electric Light & Power Company's station, 187th Street near Broadway. Paper: "Electric Street Lighting in New York" by W. T. Dempsey. Moving pictures showing New York method of installation, construction and maintenance and lantern slides demonstrating how the equipments have been standardized for the various types of streets were shown. After the meeting an automobile inspection tour was made through Manhattan and the Bronx to see interesting exhibits characteristic of the various types of New York installations.

PHILADELPHIA SECTION

June 16, 1916, Engineers' Club, 1317 Spruce Street, Philadelphia, Pa. Paper: "A Century of Illumination in Philadelphia" by William J. Serrill. The paper was illustrated by lantern slides and discussed by Messrs. Hoadley, Maxwell, Bond, Russell, Douglass, Moon, Calvert, Ferree, Lee, Snyder and Ely. Both the dinner, which was held before the meeting at the Engineers' Club, and the meeting were well attended by members and ladies. Prof. Geo. A. Hoadley announced the result of the election of officers. A vote of thanks was extended to the retiring chairman.

PITTSBURGH SECTION

June 23, 1916, Pittsburgh Athletic Association. A description of some of the lighting effects at the Panama-Pacific Exposition was given and fully illustrated by Mr. M. C. Turpin. This was the final meeting of the season and the ladies were especially invited.

New Members.

At a meeting of the Council held June 8, 1916, the following applicants were elected members:

CRAWFORD, DAVID FRANCES
General Superintendent, Motive Power, Pennsylvania Line West of Pittsburgh, 1002 Penna. Station, Pittsburgh, Pa.

ELIOT, EDWARD M.
Assistant Engineer, Percival & Jones, 810 Olive St., St. Louis, Mo.

McNALLY, EDWIN F.
Executive Secretary, Drexel Institute, 32nd and Chestnut Sts., Philadelphia, Pa.

MÜLLER, HENRY N.
Superintendent of Distribution, Duquesne Light Co., 435 Sixth Ave., Pittsburgh, Pa.

Transfer to Grade of Member.

The following associate member has been transferred to the grade of member:

THOMAS, N. WILEY
Chief, Bureau of Gas, City of Philadelphia, 332 City Hall, Philadelphia, Pa.

New Associate Members.

At a meeting of the Council held June 8, 1916, the following applicants were elected associate members:

ANDREWS, ROBERT M.
Passenger Agent, Baltimore & Ohio Railway Co., P. O. Box 353, Parkersburg, W. Va.

BAKER, E. D.
Fine Science Laboratories, Roffy-Baker Co., Highland Bldg., Pittsburgh, Pa.

BROWNLEE, EDWARD G., JR.
Superintendent, Canadian Sunbeam Lamp Co., Ltd., 221 Dufferin St., Toronto, Canada.

FOLZ, ARTHUR FREDERICK
Assistant Engineer, L. B. Marks, 103 Park Ave., New York, N. Y.

GRIGSBY, BERTRAM JAMES
Electrical Engineer, Managing Director, Benjamin Electric, Ltd., 1a Rosebery Ave., London, England.

HURLEY, WALLACE P.
Commercial Engineer, Westinghouse Electric & Manufacturing Co., East Pittsburgh, Pa.

LUKES, GEORGE HOLT
General Superintendent, Public Service Co. of Northern Illinois, 72 W. Adams St., Chicago, Ill.

MACDONALD, RUSSELL CARRIGAN
Engineering Department, National X-Ray Reflector Co., 235 W. Jackson Blvd., Chicago, Ill.

NEEL, WILLIAM TRENT
Electrical Engineering, Philadelphia Electric Co., 1000 Chestnut St., Philadelphia, Pa.

ORR, WILLIAM JOHNSTON
Salesman, Canadian Westinghouse Co., Ltd., 1207 Traders Bank Bldg., Toronto, Canada.

ROFFY, J. T.
Fine Science Laboratories, Roffy-Baker Co., 203 Highland Bldg., Pittsburgh, Pa.

SCHWARTZMAN, B.
Designer, New York Gas & Electric Appliance Co., 569 Broadway, New York, N. Y.

SHAY, JOHN P.
General Foreman, United Electric Light & Power Co., 130 E. 15th St., New York, N. Y.

STAIR, J. L.
Chief Engineer, National X-Ray Reflector Co., 235 W. Jackson Blvd., Chicago, Ill.

SULLIVAN, N. C.
Engineering Department, National X-Ray Reflector Co., 235 W. Jackson Blvd., Chicago, Ill.

Results of 1916 I. E. S. Election.

The Committee of Tellers met June 2, 1916, in the general offices of the society, and counted the votes of the 1916 annual election. The results reported by the committee showed that the following officers of the society and its several sections were elected for various terms beginning October 1, 1916:

President, Wm. J. Serrill; general secretary, C. E. Clewell; treasurer, L. B. Marks; vice-presidents, M. G. Lloyd, Geo. S. Crampton, and T. H. Piser; directors, C. A. Luther, D. McFarlan Moore, and P. G. Nutting.

Chicago Section—Chairman, Otis L. Johnson; secretary, James J. Kirk; managers, A. L. Arenberg, A. O. Dicker, H. M. Frantz, E. H. Freeman, and F. A. Rogers.

New England Section—Chairman, S. C. Rogers; secretary, R. G. Hudson; managers, J. W. Cowles, David Crownfield, C. A. B. Halvorson, Gifford Le Clear, and George P. Smith.

New York Section—Chairman, W. Greeley Hoyt; secretary, Norman D. Macdonald; managers, Wm. J. Clark, Alexander Maxwell, W. H. Rolinson, John B. Taylor, and Edward Wray.

Philadelphia Section—Chairman, Robert B. Ely; secretary, T. Elmer Moon; managers, P. H. Bartlett, John R. Hare, Geo. A. Hoadley, T. J. Litle, and Walter R. Moulton.

Pittsburgh Section—Chairman, S. G. Hibben; secretary, L. O. Grondahl; managers, Allan Bright, R. B. Chillas, T. W. Rolph, R. H. Skinner, and M. C. Turpin.

THE

EDISON-DECENNIAL NUMBER

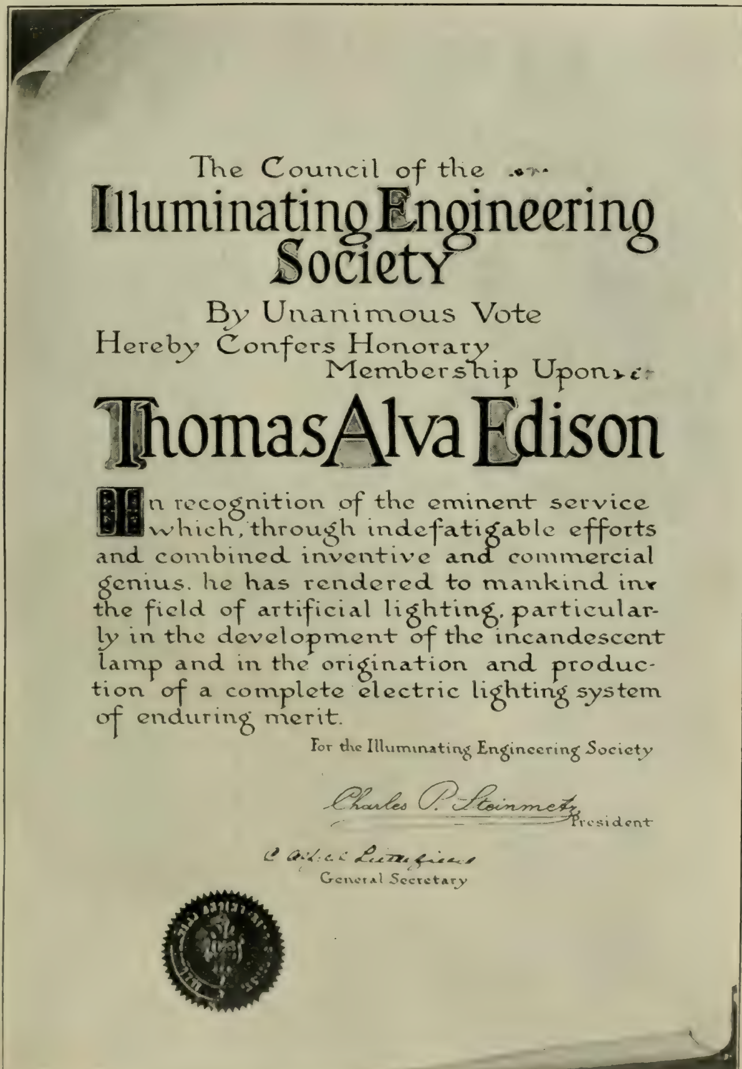
In Commemoration of
the award of honorary membership
to THOMAS ALVA EDISON

In Celebration of
THE TENTH ANNIVERSARY
of the FOUNDING of the
ILLUMINATING
ENGINEERING
SOCIETY

Committee on Awarding Honorary Membership to Thomas Alva Edison

Hon. John Purroy Mitchel, *Honorary Chairman*
Mr. Arthur Williams, *Chairman*

Mr. Walter R. Addicks
Mr. U. N. Bethel
Mr. William H. Bradley
Mr. Nicholas F. Brady
Mr. A. W. Burchard
Dr. Nicholas Murray Butler
Mr. Newcomb Carlton
Mr. Robert A. Carter
Mr. J. J. Carty
Mr. Charles H. B. Chapin
Dr. Thomas W. Churchill
Mr. Charles A. Coffin
Mr. George B. Cortelyou
Mr. Dudley Farrand
Mr. F. M. Feiker
Mr. Wilbur C. Fisk
Mr. Lewis B. Gawtry
Mr. Cass Gilbert
Mr. E. R. Graham
Mr. George H. Guy
Mr. Thomas Hastings
Mr. Frank Hedley
Mr. W. Greeley Hoyt
Dr. A. C. Humphreys
Mr. F. L. Hutchinson
Dr. M. R. Hutchison
Mr. T. I. Jones
Mr. Clarence L. Law
Mr. J. W. Lieb
Mr. T. C. Martin
Mr. William H. Meadowcroft
Mr. T. M. McCarter
Mr. James H. McGraw
Mr. H. B. McLean
Mr. Joseph B. Murray
Mr. Thomas E. Murray
Mr. Walter Neumuller
Mr. L. A. Osborne
Mr. George F. Parker
Mr. J. E. Phillips
Mr. Charles W. Price
Mr. Geo. G. Ramsdell
Mr. C. W. Rice
Mr. E. W. Rice
Mr. Theodore P. Shonts
Mr. Frank W. Smith
Dr. B. W. Stilwell
Mr. George A. Taber
Mr. C. G. M. Thomas
Mr. G. E. Tripp
Mr. Theodore N. Vail
Mr. J. M. Wakeman
Mr W. F. Wells
Mr. Frederick Whitridge
Col. Timothy S. Williams
Hon. William Williams


The Council of the

Illuminating Engineering Society

By Unanimous Vote
Hereby Confers Honorary
Membership Upon

Thomas Alva Edison

In recognition of the eminent service which, through indefatigable efforts and combined inventive and commercial genius, he has rendered to mankind in the field of artificial lighting, particularly in the development of the incandescent lamp and in the origination and production of a complete electric lighting system of enduring merit.

For the Illuminating Engineering Society

Charles P. Steinmetz
President

General Secretary

Certificate of Honorary Membership.

Acceptance of Honorary Membership by Thomas Alva Edison.

MRS. THOMAS ALVA EDISON

THOMAS ALVA EDISON JOHN W. LIEB

TRANSACTIONS
OF THE
Illuminating Engineering Society

VOL. XI | AUGUST 30, 1916 | NO. 6

ADDRESS OF WELCOME.*

BY JOHN PURROY MITCHEL.

Mr. Chairman, Mr. President, ladies and gentlemen of the Illuminating Engineering Society: For the City of New York I take great pleasure in extending to you a very warm welcome. You have come to this convention on the tenth anniversary of the founding of your Society. Upon that event I congratulate you. Your Society is young, and so is your profession, but though both are young they represent together, one of the greatest industries and professions that we have to-day in this country; one upon which we depend for comfort and convenience, as largely as upon any.

New York City has learned intimately how fully, how completely, it must depend upon its engineers for all kinds of service and for all its great constructive works. Now and then I have heard men say that we have too many engineers in the city service and that they are inclined rather to promote expenditure than to control and limit it, and yet I always notice that whenever a great work is in contemplation, or about to be undertaken, when we want a close analysis, the final facts upon which judgment must be predicated, we go to the engineers to get those facts and we entrust to the engineers the construction of those great works, and I have come to have a very lively appreciation of their value and their services to this community.

What I have said is equally true in the field of illumination. The city's direct interest in that work is measured perhaps most easily and directly by the amount of its expenditure. I have not the exact figures in mind, but it is approximately five million

* The opening address at the mid-winter convention of the Illuminating Engineering Society, New York, February 10, 11, 1916.

dollars a year that New York City spends upon municipal lighting. When this administration took office we determined that this field of expenditure required a special and a new analysis. We directed study to it with the result that during the two years of the present city administration, the illuminating engineers of the Department of Water Supply, Gas and Electricity, which has control over municipal lighting, have increased the amount of lighting by 100 per cent. and decreased the expenditure by about half a million dollars. That is a municipal achievement. It is an achievement on the part of the engineers in the Department of Water Supply, Gas and Electricity, who have been entrusted with this work, and an achievement to the credit of the administration of that department, and all who have had to do with making the analysis and making up the budget.

The field of municipal lighting will not contract, it is bound to expand. We will need more and more lighting in the City of New York, as we will in all of the great cities. We will need better lighting. We must find the cheapest way of lighting our great cities, and so the field of your activities is very great. Of course I speak to you from the municipal point of view, that is the branch of your work that interests me most. You are going to grow, your work is going to become more important and the opportunity for your services to the communities of our country will be expanded as time goes on. I congratulate the Society and the profession upon the achievements of this ten years and I extend to you my felicitations and the hope that your work will go on, that the Society will continue to grow and that the opportunities for your service to your fellow citizens will continue to expand.

RESPONSE TO ADDRESS OF WELCOME.*

BY A. E. KENNELLY.

Mr. Mayor, we are proud to have you open this convention which commemorates the decennial epoch of the Illuminating Engineering Society. We are, as you have said, a young Society, but we have all the enthusiasm and wholeheartedness of youth. We form a branch of the great brotherhood of engineers, that army of trained men who endeavor to serve the community by the applications of science, through arithmetic and economics, to the benefit of society. But we differentiate ourselves to some extent from the general brotherhood of engineers, in the particular that we owe service not only to the dictates of arithmetic and of economics, but also to the guidance of esthetics and of hygienics. If, looking around at night, you see an illuminant that is not effective, not economical, inharmonious, unpleasing, or injurious to the eye, believe us that it is not in accordance with the canons of our art. We have to serve the taste as well as the utilitarian needs of the public; so that where we fail to produce artistic results, we fail to that extent in the performance of our duty.

Although we are but a young profession, we look back with pride on the early development of our craft. The Metropolitan Museum of Art of New York is justly proud of possessing a tomb which rested for forty-five centuries on the bank of the lotus-loving Nile; but long before the Nile can have irrigated Egypt, the first illuminating engineer had profoundly modified human history. We do not know where this tomb may have been made. The geologists have not yet informed us whether it is in the pleistocene or in the pleiocene, but we know just where it should be sought for. Where calcined bones are first associated in the rocks with human remains, marks the stratum and the date of the work of that primitive illuminating engineer who first permanently imprisoned fire for man, wrested night from darkness, and founded the domestic hearth. Him the Greeks

* Given in response to the opening address at the mid-winter convention of the Illuminating Engineering Society, New York, Feb. 10, 11, 1916.

adored under the name of Prometheus, the snatcher of fire from Heaven.

Turning to times more recent, the history of artificial illumination would be as incomplete without reference to New York as the history of New York would be without reference to the development of illuminating engineering. Even the great Bartholdi Statue of Liberty, at the sea portal of New York, may claim to represent the genius of liberty working through the ancillary genius of illumination. What city in the world to-day is more proud of its artificial illumination than New York, in its halls, its homes, its parks and avenues, its great white way? It may be lavish, but at least it is magnificent. We congratulate you Sir, on being Mayor of so brilliant a city.

We look forward to the hope and expectation of a great future for this organization of ours, since, in our short ten years of existence, we have had so much to commemorate. America is not a country which arrogates to itself all knowledge and all achievement. "We are the people, and knowledge shall die with us" is a refrain unfamiliar to American lips. Proud of our mingled heritage of race, we are glad to recognize and acclaim the contributions from other countries and other languages to our own special science and art. Nevertheless, we believe that, in contempt of all question, an impartial examination into the history of artificial lighting will show that America has taken a fair and leading part in its development. We signalize to-night the achievements in this direction of Mr. Edison, as an honorary member of our Society, a man whose name is associated, as a household word, with the rise, the progress and attainments of incandescent lighting.

We regret, Mr. Mayor, that your many duties will probably not permit you to stay with us and take part in the discussions of this convention. Shall we not hope, however, that in the future it may be shown that lamps shall shine a little the better or the brighter, and that the knowledge and application of illuminating engineering shall be some little more powerful and useful because of this convention which you have here so happily inaugurated.

TENTH ANNIVERSARY OF THE ILLUMINATING ENGINEERING SOCIETY.*

BY L. B. MARKS.

Synopsis: This historical address traces the development of the Illuminating Engineering Society from its inception in 1906 up to the present time. The author reviews those factors which made necessary the organization of the Society and in chronological order he shows the building up of the art and science of illumination as fostered by the activities of the Society. Specific references are made to the excellent work done by the various committees and to the dissemination of knowledge through the publications of the Society.

Ten years ago at the first meeting of the Illuminating Engineering Society, it was my privilege to address the members on the aims and objects of the Society and the scope of its work. Today it is my privilege, in celebrating our tenth anniversary, to cast a brief retrospect over the work of the Society during the past decade and to contrast the conditions that prevailed then and that obtain now.

From a small group of enthusiasts there has sprung a national society with a membership of thirteen hundred, having representatives from nearly every state in the Union and from several foreign countries.

Before the foundation of the Society there had been no attempt to gather into one collection, the information and data relating to light and illumination. Such information as existed on this subject was scanty, widely scattered and not available for general use. Furthermore there had been no co-operation between the various bodies and individuals that were interested in the development of the science and art of illumination. The electrical engineer, when the subject came up for discussion at all, discussed it before the electrical society, the gas engineer before the gas society, the architect before the architectural society, the physicist before the physical society, etc.

The Illuminating Engineering Society brought all of these

* A historical address given at the mid-winter convention of the Illuminating Engineering Society, New York, February 10, 11, 1916.

elements together; the physicist, the physiologist, the psychologist, the electrical engineer, the gas engineer, the architect, the fixture designer, the manufacturer, the school superintendent, etc. Not only have all of these been represented in the membership of the Society and its committees, but in the management as well,—a plan which has yielded results that would have been impossible without such co-operation. The subject of lighting was discussed from all points of view,—hygienic, economic, esthetic—in technical papers presented by individuals, committee reports and discussions at meetings; thus giving to the world a comprehensive treatment of the science and art from every standpoint, so that in ten years we have gathered in the printed TRANSACTIONS of the Society, volumes aggregating 8,000 pages, constituting the most complete reference library on illumination to be found anywhere.

Before the Society was organized, lighting was largely a matter of guessing. Now it is a matter of science, and the rule of thumb that existed before has given way to definite calculations which may be depended upon to ensure the same lighting result in all cases under stated conditions. This does not mean that the Society has been interested only in the scientific side of the question. On the contrary it has laid great stress on the esthetic side and has recognized the general principle that science and art should go hand in hand.

During the past ten years the lighting art has changed in many ways; new types of lamps have displaced the old; new lighting systems have been introduced; new instruments have been designed to measure light and lighting effects. For these advances in the art the members of the Society may justly claim a large measure of credit.

In incandescent lighting, the carbon lamp has made way for the tungsten, which in its latest form gives six times the light of the former with the same expenditure of energy. In gas lighting, the open flame burner has given way to the mantle burner with the greatly increased steadiness and light-producing efficiency of the latter. In arc lighting, the enclosed arc lamp which displaced the open arc, has in turn been displaced by magnetite and flame arc lamps and by gas-filled tungsten lamps.

The past decade has also witnessed notable changes in systems of lighting, both electric and gas; the most striking has been

the growing use of so-called semi-indirect and indirect systems of lighting in which the lamps are concealed from view and the illumination is derived largely or wholly by reflected light. The beautiful lighting effects produced at the Panama-Pacific Exposition were made possible by the use of concealed high-efficiency lamps in powerful reflectors.

Ten years ago the system of general lighting was rarely used, the idea being quite prevalent that strictly local lighting, such as would be obtained for example from a lamp placed close to the work without other lighting in the room, was a good plan of lighting. The fallacy of this plan for many purposes has been shown, and to-day we find general illumination the rule rather than the exception, especially in factories and workrooms.

In street lighting we have noted the development of so-called white ways. The greatly increased efficiency of lamps has led not only to better street lighting, but to illumination of building exteriors and outdoor spaces which heretofore were not illuminated at night, as for example, tennis courts, baseball fields, etc.

Following the improvements in lamps, progress has been made in the production of artificial daylight on a practical, though limited scale. We are no longer dependent upon the sun for daylight quality of illumination,—in fact, in some classes of work where fine color discrimination is vital, as in dye works for example, we have actually improved upon daylight conditions, because our artificial daylight is of the same quality as the natural light and is absolutely constant and available twenty-four hours a day. It is now practical to install in stores, artificial daylight equipment that will permit of matching colors as accurately as by natural light. Art galleries may be equipped with lighting facilities to exhibit paintings in artificial daylight,—an accomplishment which the artist has long sought.

The development of lighting glassware, shades and reflectors, has kept pace with the development of lamps and systems of lighting. The artistic glassware now available for various classes of lighting is in striking contrast to the crude product of ten years ago. The fundamental principle of all of the more effective types of modern globes and shades for both gas and electric lamps is that the glass shall be sufficiently diffusing to hide the lighted lamp from view.

If the Illuminating Engineering Society had served no other purpose than to bring about the proper shading of lamps and diffusing of light, its record for the past ten years would have sufficiently justified its existence. In the great work of the conservation of vision for which this Society stands, the principle of shading and diffusing the light of the lamp has been enunciated broadcast by the members of the Society and has reached the ears of a large part of the public. Ten years ago the bare lamp was the rule and the properly shaded lamp the exception. To-day, thanks to the propaganda of the Society, the shaded lamp is coming to be the rule and the bare lamp the exception.

In it reciprocal relations with other societies by means of joint meetings, exchange of speakers, etc., the Illuminating Engineering Society has set a standard for which no precedent exists. Joint meetings have been held with gas and electric associations, architects, municipal art societies, painters, oculists, ophthalmologists, medical associations, school and library associations, factory boards, societies for prevention of blindness, safety associations, etc. This list shows the many-sidedness of the problems of illumination.

Ten years ago an illuminating engineering department of an electric or gas company was unheard of. To-day, as a direct result of the activities of the Illuminating Engineering Society, practically every large public service company in the country has its illuminating engineering department.

The Society through its committee on nomenclature and standards, has given to the world definite terminology without which it was impossible to speak in language that all students of the science could understand. The standardized rules formulated by the Society have been adopted bodily by the American Institute of Electrical Engineers and other technical organizations. These constitute the authoritative rules on the subject of illumination. At the initiative of our Society an international standard of candlepower was agreed upon.

Great Britain and Germany both followed the example of the United States in organizing illuminating engineering societies and all three of these countries, together with other leading countries are represented in the international committee on illumination

which was organized to bring about international agreement on mooted questions in lighting.

The Society through its research committee has suggested needed research work in lighting. This work has been carried out by private laboratories and others who have contributed the results to the TRANSACTIONS of the Society. There has been close co-operation with the United States Bureau of Standards at Washington, which body has been represented at every convention of the Society.

Through its committee on glare, the Society has been studying one of the most complex subjects that have to do with lighting and with the prevention of eyestrain, and has accomplished much. In its campaign for minimizing eyestrain in the schoolroom, the Society directed attention to the bad effects of glossy surfaces and has succeeded in influencing school boards to provide proper lighting facilities, and also to furnish books with mat or dull surface paper only. The Society has set an example by printing its own TRANSACTIONS including the illustrations on dull finished paper.

Other questions relating to proper lighting conditions in the schoolroom, including orientation, window openings, direction and diffusion of natural and artificial light, finish of furniture, trim, blackboards, etc., have been studied in great detail and are treated in the "Code of Lighting for Schoolrooms," which has been for two years in course of preparation by the Society and will soon be issued.

The first attempt made by the Society to gather into one group a co-related series of technical lectures covering all phases of the science and art of illumination was made in 1910 when a course of lectures on illuminating engineering was given at Johns Hopkins University at Baltimore, under the auspices of the Society. This course of lectures gave to illuminating engineering a definite status.

Progress in the practical art has been so rapid that the Council of the Society has arranged for a new course of lectures on the same subject to be given in the fall of this year at the University of Pennsylvania.

The first attempt on the part of the Society to address the public directly in any official publication was the preparation and

distribution of the primer entitled "Light, Its Use and Misuse." The primer was reprinted in whole or in part in many journals and daily papers throughout the United States and in foreign countries. In the United States alone the copies distributed by the Society and the reprints have reached several million people.

The educational work of the Society in connection with lectures written in popular language for the public, is now well under way. These lectures have been prepared on such subjects as the lighting of the store, the lighting of the workroom, the lighting of the home, etc. The lectures, together with illustrative lantern slides are submitted to interested persons throughout the country for presentation before non-technical associations and meetings.

The Society has published and spread broadcast the results of investigations looking to the prevention of accidents by proper lighting. Recent reports of life insurance companies testify to the valuable and effective work the Society has done in this field.

A "Code of Lighting for Factories, Mills and Other Work Places" was issued last year by the Society and was the first official publication that contained specifications for standard requirements of light intensity for different classes of work. This code is intended to serve as an aid to legislative bodies and factory boards, public service commissions and others who are interested in enactments, rules and regulations for better lighting, and is also intended for the industries themselves as a practical working guide in the remodeling of existing lighting installations and the design of new installations.

The value of the Society's work in connection with legislation regarding lighting, is exemplified in the laws of the State of New York, on the lighting of factories and workrooms. These laws were the first to provide specifically against glare in the eyes of the workmen. The laws were drawn up in accordance with recommendations of our Society. It is gratifying to add that the Society is now actively co-operating with legislators and boards in other states in the preparation of working codes of lighting.

The Society has accomplished a valuable work in preparing working exhibits showing, side by side, the right way and the wrong way to light the schoolroom, the living room, the workroom, etc., and illustrating the principles of good lighting. These

exhibits, consisting of miniature lighting installations in portable booths, have been shown in public places, electrical shows, etc., in various cities where they have been seen by hundreds of thousands of people.

It would be impossible in this brief retrospect to do justice to the tremendous amount of work accomplished by the Society and to the ramifications of this work. Its greatest accomplishment after all, perhaps, is that it has set the public thinking about the importance of good lighting and has opened the eyes of the average man to a vital question that had not before received the consideration it merited.

Much as has been done in the ten years of our existence, we have made only a beginning and the possibilities of our value to the community loom up bigger and bigger with each succeeding year. The country's lighting bill has increased by leaps and bounds, and is now estimated at a thousand million dollars a year. The Society is of great value to the public in showing how waste in this expenditure may be avoided, but the economic side of its activities, viewed from the narrow standpoint of dollars and cents, is subordinate to its great work in spreading the gospel of hygienic, safe and pleasing illumination and in conserving eyesight and life itself.

A big field is still before us in acquiring and disseminating knowledge of the architectural and decorative requirements of illuminating design; in laying the foundation of college courses in illuminating engineering and courses for practitioners; and in the extension of educational work reaching the public directly.

We have reached only about one-tenth of the theoretical limit of light-giving efficiency of lamps, and the possibilities of future developments in lessening the cost of lighting and widening the application of artificial light are tremendous.

In extending its services to states and municipalities and to legislative boards in advising as to the technical requirements of future legislation regarding lighting, the Society has before it a field of vital interest and importance to every citizen. This field includes not only artificial lighting but daylight.

As yet our work has hardly touched upon the pressing problem of city planning with reference to orientation of streets and buildings, and building height limitations, to insure not only

greater beauty but more daylight and sunlight in buildings. From a hygienic standpoint the value of future work in this direction will appeal to everyone who gives the matter serious thought.

The problems of lighting are so many-sided that only a glimpse of the vast field that lies before the Society can be given here. The Society stands first and foremost for co-operation in all that concerns the advancement of the science and art of lighting. It aims to be a clearing house for authoritative information relating to light and illumination. It has no affiliation with any commercial organization and offers its services freely to the public and to the nation.

PRESENTATION OF HONORARY MEMBERSHIP TO THOMAS ALVA EDISON.*

BY JOHN W. LIEB.

The forward march of civilization through the ages is indicated in no more striking manner than in the desire of the human race for more and more light. Starting with the smoky pine knot and resinous strips of the cave man, followed by the shallow clay basins and dingy oil lamps of Egypt, Greece and the Far East, by progressive steps we reach the beautiful and effective lamps and candelabra so strikingly evidenced in the buried treasures of Pompeii and Herculaneum.

Coming to a later date we are struck by the fact that there is a substantial historical basis for the view that the characteristic phrase, the Dark Ages, used to designate an epoch in history, indicates not merely a period during which the steady advance in civilization of the human race was temporarily checked, but literally also an age of gloom, for the luxury and brilliancy of Greece and Imperial Rome, bringing with it evidences of a desire for adequate illumination, was followed in the so-called Dark Ages by a retrogression to crude and ineffective means for supplying artificial light.

The Renaissance, with the gorgeousness and sumptuousness of its regal and ducal courts, brought with it also an increased demand for more light, confined largely, at first, to display at brilliant festivals and princely celebrations. About this time the candle first made its appearance, and by its flickering gleams and clustered groupings added mystery and pomp to religious and state ceremonials.

We have ample evidence in the works of that master mind and extraordinary genius, Leonardo da Vinci, of the attention that was being paid during this time to the providing of bizarre illuminating effects for gorgeous pageants and in the improvement for general interior illumination of the crude lamps, by

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the addition of chimneys, reflectors and even bull's-eye lenses. In the centuries immediately following, important advances were made in the application of improved burners for oil lamps using animal and vegetable oils, in which connection we recall the familiar names of Argand, Carcel and Hinks. Improved means of feeding the oil to the wick appeared in various forms of pump and clock lamps, of which the moderateur type survives in the still popular so-called student lamp.

In the early part of the last century, notable progress was made in the field of lighting by oil lamps, due to the impetus given by the discovery of mineral oil, first used as an illuminant in 1853, and giving rise in later years to steady, efficient and powerful oil lamps. The candle industry had also in the meantime been making progress, resulting in the displacement of the old tallow dip and wax candles with the improved stearic acid and paraffine candles, which are still popular for special uses and which have given us our unit value of illuminating effect, the parliamentary standard candle.

In the latter part of the eighteenth and early part of the nineteenth century, the manufacture of illuminating gas had progressed to such a stage that William Murdock in 1802 was able to light the famous Soho Foundry of Bolton & Watt, at Manchester, and there was exhibited in 1807 on Pall Mall, London, a complete system of street lighting by gas. Contented at first with the simple but inefficient fish-tail and bat wing burners, the gas industry soon appropriated to its uses the Argand and Bunsen principles, also preheating the gas, and perfected intensive and regenerative gas burners came into general use during the years 1878 and 1880, the period in which we are particularly interested this evening.

A new and radically advanced type of illuminant had its birth, however, when Sir Humphrey Davy in 1809 produced a brilliant electric spark from the batteries of the Royal Society; then followed a period of experimentation and research with the electric arc, applying first the carbon from gas retorts to the current produced by grouping battery cells, to which an immense impulse was given by the advent of that cheap and powerful source of current, the dynamo-electric machine. We have but little time

to consider the historical progress of this new illuminant, with which the names of Carré, Foucault and Dubosq are associated, and which had reached an advanced stage of development about 1878-1879, as exemplified in the Serrin, Lontin, Farmer, Heffner von Alteneck, Crompton, Gulcher and other lamps and the lighting systems of Siemens, Brush, Thomson-Houston, Weston, Schuyler, etc. The open arc lamp by this time having attained its full efficiency, there remained for improvement only the details of functional machinery, and lamp mechanism. Paralleling this development, there was much done, also, in the direction of experimentation and application of inventive ingenuity in the study of so-called semi-incandescent lamps, of which the Soleil and Werdermann lamps and the Jamin and Jablochkoff electric candles were typical, the latter even attaining a certain degree of commercial application.

Very soon after the voltaic battery became available, it appeared that a heavy current would heat and bring to brilliant incandescence metals in the shape of thin strips or wires, and platinum from its high fusing point became the material on which early inventors based their hopes for a new illuminant. Carbon also, from its elevated fusing point and high resistance, was among the promising materials, and experiments were made with carbon, in rods, plates and also pencils in almost wirelike attenuation, but never reaching the extreme tenuity of a "filament;" also platinum wire—often alloyed with iridium—rendered incandescent in the open air and in glass globes, sometimes evacuated of air and sometimes filled with neutral gases, was the subject of endless researches and investigations. We have time only in this connection to mention the names of such pioneer workers in this field as Jobard, Depretz, de Changy, Starr, Roberts, Lodyguine, Konn, Kosloff and De Khotinsky.

These experiments conducted by a number of enthusiastic and tireless workers held much of promise and, could they have had from the beginning the convenient and potent source of electrical energy which the dynamo subsequently made available, the goal would probably have been reached much sooner.

It has been necessary to sketch briefly—altogether too superficially to be historically satisfactory—the situation as regards

artificial illumination—the "state of the art," as it were—for without such a statement it would be impossible to correctly assign a proper place, historically, to the man to whose genius we are paying homage this evening. Although we are not here to consider the work of Mr. Edison along all of the many paths of research and invention in which he has produced so much and of such great value, we cannot obtain a just appreciation of his work in the field of illumination, with which we are primarily concerned at this time, without giving some consideration, superficial as it must be, to his work in related fields, which served as a preparation for his work in the special sphere which interests us this evening.

In the little village of Milan, Ohio—it will be exactly *69 years ago to-morrow,* February 11, 1916—there was born our honored guest of this evening, Thomas Alva Edison. Time presses upon us so that we must regretfully omit a sketch of his early life as a schoolboy, newsboy and embryonic journalist and newspaper editor developing into the dabbler in chemical and physical experimentation, and finally the expert telegrapher, until he reaches the Patent Office with his first patent—the electro-graphic vote recorder—taken out October 13, 1868. Then followed a long series of inventions and improvements by him in telegraph systems and apparatus, including the stock printer, district telegraph and chemical telegraph, the wonderful duplex, and finally his crowning telegraphic achievement, the brilliant quadruplex system of telegraphy.

Late in 1877 appeared his carbon button transmitter, that most necessary and invaluable auxiliary of Alexander Graham Bell's epoch-making invention. In a short time there was announced the invention of that scientific marvel which has in later years, through its commercial development, made available to every home the works of the musical geniuses of the world and their interpretation by instrumental virtuosi and song birds, that most genial perhaps of all of Edison's inventions, the phonograph.

On October 14, 1878, there appeared Mr. Edison's first invention in the field of electric lighting—a thermostatic regulator—for use in combination with a platinum-iridium lamp to keep the current to a safe value by the insertion of a shunt resistance

operated by the mechanical expansion of the incandescent conductor.

Because Mr. Edison did not always choose to follow the paths beaten by his predecessors, because he often sought out lines of investigation and experiment which were original and untried, because he looked for the solution of the problems before him in the unobvious, the unexpected, he has been considered by many as a purely empirical worker, a lucky experimenter, the embodiment of the cut-and-try, haphazard method of research and investigation. Nothing could be further from the truth, as witness the stern logic with which he pursued relentlessly and industriously his fundamental idea of finding the complete electrical analogue of the gas lighting system.

In launching into this field Edison did not proceed as others, who were at this time investigating and experimenting to find a practical solution of that *ignis fatuus* of the time—the subdivision of the electric light—one group of investigators working at details of the lamp, another group at the development of the dynamo-electric machine, still another at regulating and controlling devices, etc. He started out with the broad conception of developing a complete system in its every detail, based on the solid and broad foundation of precedent established by the intensely practical and successful gas industry. Right from the very beginning he had ever before him this broad conception—and in carrying out this idea he planned a complete system from the electric generators, giving consideration even to special types of boilers and engines adapted to drive them, down to the lamp and other utilization devices, not omitting any of the innumerable details inside the station, such as ammeters, voltmeters, regulators and switching gear, and outside of the central station underground conductors, feeders, mains, junction and coupling boxes, service switches and cutouts, safety fuses, meters, wiring and wiring devices such as safety plugs, circuit switches, chandeliers, brackets, sockets, lamps, etc., in fact, the number of devices he developed is legion.

Let us now avail ourselves of Mr. Edison's own words—which he used some years ago to describe the problem which he, in 1878, set out to solve:

"We soon saw that the subdivision (of the electric light) never could be accomplished unless each light was independent of every other. Now it was plain enough that they could not burn in series. Hence they must burn in multiple arc. It was with this conviction that I started. I was fired with the idea of the incandescent lamp as opposed to the arc lamp, so I went to work and got some very fine platinum wire drawn. Experiment with this, however, resulted in failure, and then we tried mixing in with the platinum about 10 per cent. of iridium, but we could not force that high enough without melting it. After that came a lot of experimenting—covering the wire with oxide of cerium and a number of other things.

"I then took a cylinder of zirconia and wound about a hundred feet of the fine platinum wire on it coated with magnesia. What I was after was getting a high resistance lamp, and I made one that way that worked up to 40 ohms. But the oxide developed the phenomena now familiar to electricians, and the lamp short-circuited itself. After that we went fishing around and trying all sorts of shapes and things to make a filament that would stand. We tried silicon and boron, and a lot of things that I have forgotten now. I never thought in those days that a carbon filament would answer, because a fine hair of carbon was so sensitive to oxidation. Finally, I thought I would try it because we had got very high vacua and good conditions for it.

"We sent out and bought some cotton thread, carbonized it, and made the first filament. We had already managed to get pretty high vacua and we thought, maybe, the filament would be stable. We built the lamp and turned on the current. It lit up, and in the first few breathless minutes we measured its resistance quickly and found it was 275 ohms—all we wanted. Then we sat down and looked at that lamp. We wanted to see how long it would burn. The problem was solved—*if* the filament would last. The day was—let me see—*October 21, 1879*. We sat and looked, and the lamp continued to burn, and the longer it burned the more fascinated we were. None of us could go to bed, and there was no sleep for any of us for forty hours. We sat and just watched it with anxiety growing into elation. It lasted about forty-five hours, and then I said, 'If it will burn that number of hours now, I know I can make it burn a hundred.' We saw that carbon was what we wanted, and the next question was what kind of carbon. I began to try various things, and finally I carbonized a strip of bamboo from a Japanese fan, and saw that I was on the right track."

Let us complete the picture by quoting from Mr. Edison's patent specification, which was the outgrowth of this successful experiment of October 21, 1879, the date universally recognized as the birthday of the commercial incandescent lamp, because this specification is couched in Mr. Edison's own language.

"The object of this invention is to produce electric lamps giving light by incandescence, which lamps shall have high resistance, so as to allow of the practical subdivision of the electric light. The invention consists in a light-giving body of carbon wire coiled or arranged in such a manner as to offer great resistance to the passage of the electric current and, at the same time, present but a slight surface from which radiation can take place. The invention further consists in placing such burner of great resistance in a nearly perfect vacuum to prevent oxidation and injury to the conductor by the atmosphere. The current so conducted into the vacuum bulb through platinum wires sealed into the glass. The invention further consists in the method of manufacturing carbon conductors of high resistance, so as to be suitable for giving light by incandescence.

"Heretofore, light by incandescence has been obtained from rods of carbon of one to four ohms resistance and placed in closed vessels, in which the atmospheric air has been replaced by gases that do not combine chemically. The leading-in wires have always been large, so that their resistance shall be many times less than the burner, and, in general the attempts of previous workers have been to reduce the resistance of the carbon rod. The disadvantages of following this practice are that a lamp having but one to four ohms resistance cannot be worked in great numbers in multiple arc without the employment of main conductors of enormous dimensions; that owing to the low resistance of the lamp, the leading-in wires must be of large dimensions and good conductors, and a glass globe cannot be kept tight at the place where the wires pass in and are cemented; hence the carbon is consumed, because there must always be a perfect vacuum to render the carbon stable, especially when such carbon is small in mass and high in electrical resistance.

"The use of gas in the receiver at the atmospheric pressure, although not attacking the carbon, serves to destroy it in time by 'air-washing' or the attrition produced by the rapid passage of the gas over the slightly coherent, highly heated surface of the carbon. I have reversed this practice. I have discovered that even a cotton thread properly carbonized and

placed in a sealed glass bulb exhausted to one millionth of an atmosphere offers from 100 to 500 ohms resistance to the passage of the current, and that it is absolutely stable at very high temperatures; that if the thread be coiled as a spiral and carbonized, or if any fibrous vegetable substance which will have a carbon residue after heating in a closed chamber, be so coiled, as much as 2,000 ohms resistance can be obtained without presenting a radiating surface greater than three-sixteenths of an inch. I have carbonized and used cotton and linen thread, wood-splints, paper coiled in various ways, also lampblack, plumbago, and carbon in various forms mixed with tar and rolled out into wires of various lengths and diameters."

Let us now consider for a moment what had been accomplished at this time up to, say, 1878-1880 in the search for a practical incandescent lamp as the most important element in the solution of the problem of the subdivision of the electric light and the opinions of leading scientific authorities as to the probability of its successful solution.

As illustrative of the views held at this time by prominent scientific men abroad we may quote an abstract from a report by Mr. John T. Sprague of London, a well known electrician of the time and writer of an authoritative electrical textbook, to the following effect:

"Neither Mr. Edison nor anyone else can override the well known laws of Nature and when he is made to say that the same wire which brings you light will also bring you power and heat, there is no difficulty in seeing that more is promised than can possibly be performed. To talk about cooking food by heat derived from electricity is absurd."

Mr. (later Sir) William H. Preece in a lecture on February 17, 1879, after discussing the problem of the subdivision of the electric current, mathematically, said: "Hence the subdivision of the light is an *ignis fatuus.*" Incidentally, it may be mentioned, Mr. Preece a year or so later became one of Mr. Edison's most enthusiastic supporters.

Dr. Paget Higgs in a book published in London in 1879 stated "Much nonsense has been talked in relation to this subject. Some inventors have claimed the power to 'infinitely divide' the electric

current, not knowing, or forgetting, that such a statement is incompatible with the well proven law of conservation of energy."

The eminent scientist John Tyndall in a lecture on the electric light delivered before the Royal Institution in January, 1879, and speaking of Mr. Edison in connection with the contemporary state of the art, said: "Knowing something of the intricacy of the practical problem, I should certainly prefer having it in Mr. Edison's hands to having it in mine."

A short time before, Professor Sylvanus P. Thompson, now one of England's most distinguished authorities in electrical science, in a lecture had stated: "This I can tell you, as the result of all experience, that any system of electric lighting depending on incandescence will utterly fail from an economic point of view, and will be the more uneconomic the more the light is subdivided."

The eminent scientist Fontaine in France about this time demonstrated to the satisfaction of the scientific world that the subdivision of the electric light was impossible of attainment and that the disintegration of carbon when made incandescent ruled it out of consideration for small burners.

Among the contemporary workers with Edison in developing the incandescent lamp may be mentioned William E. Sawyer and Albon Man, who took out their first patent June 18, 1878, for a lamp consisting of a two-part enclosing globe containing a low resistance pencil of carbon with a mechanism for feeding it as it was consumed and large spiral radiating conductors made hollow to permit of exhaustion of the air and the introduction of nitrogen gas. In a subsequent modification the carbon rod was shortened, the feed pressure being exerted from below instead of from above, and a later patent of January 7, 1879, referred to depositing dense carbon by the "flashing" process, and finally they formed carbons solely in this way.

Previous patents indicate that the lamps referred to had a resistance as low as 0.6 ohm and were therefore to be used for series and multiple series lighting and not for use in parallel, Mr. Edison's lamps for the latter purpose having a resistance, hot, of over 140 ohms.

Judge Bradley in a court opinion referring to the work of these two pioneers stated: "It seems to us that Sawyer and Man were following the wrong principle—the principle of small resistance in an incandescing conductor and a strong current of electricity and that the great discovery in the art was that of adopting high resistance in the conductor with a small illuminating surface, and a corresponding diminution in the strength of the current. This was accomplished by Edison in his filamental thread-like conductors, rendered practicable by the perfection of the vacuum in the globe of the lamp."

Hiram S. Maxim, another distinguished pioneer in this field, in 1877 constructed a platinum lamp with thermostatic regulator, which he operated from batteries and later by a dynamo, and in 1880-1881, he took out patents for a low resistance series lamp of the "stopper" or separable two-part globe type with carbons formed from paper, wood, or carbonaceous materials in a hydrocarbon vapor, and he stated "lamps of high resistance cannot well be used in any considerable number in series on account of the immense electro motive force required for passing a current through their combined resistance, and it is one of the objects of this invention to provide an incandescent lamp adapted to be used in *series* and capable of giving a large amount of light."

Mr. (later Sir) Joseph W. Swan, in England, has been credited with having had a more correct idea of the path along which the successful solution of this problem of the subdivision of electric light would lie, than any other investigator save Mr. Edison. One of his first exhibits of an incandescent lamp was made before the Chemical Society at Newcastle on December 16, 1878. It consisted of a slender rod or pencil of carbon suspended between platinum leading-in wires in an exhausted glass globe, but as was stated later by Lord Justice Fry: "The burner was not so slender that it could be described as a 'filament' and it burned but a short time, the carbon rod bending from the excessive current."

A second lamp exhibited on February 3, 1879, lasted for some twenty minutes and in some lamps shown as late as October 20, 1880—some nine months after the publication of Edison's filament patent—he still utilized a short and thick low resistance carbon only suitable for series lighting, and he states that he

understands Mr. Edison's lamp to have a high resistance much higher than he (Swan) believed safe in an incandescent burner. In a further statement made at this time, referring to the grouping of his lamps in series of ten to fifty or more, he stated: "There is no escape that I know of from this dilemma, *viz.*: that if we must make our unit of light larger than necessary for a great many purposes and so give us the idea of extensive division and extensive distribution in order to gain these points, we must group the lamps in the manner I have proposed" (*i. e.,* in series).

Another English experimenter at this time (1878-1880), St. George Lane-Fox, seemed to have a more definite conception of the importance of using a filament of high resistance and small radiating surface, but while the specifications in his patent indicate a grasp of the theory, his platinum-iridium wire conductor in nitrogen gas, wires coated with finely divided asbestos and fire clay and also his luminous bridge of combined conducting and non-conducting substances, were all of insufficiently high resistance for multiple arc distribution.

In 1881 Mr. Lane-Fox in discussing the problem made the following important statement:

"I think great credit is due Mr. Edison for having stated from the first that it was possible to introduce a system of electric light that could be so distributed and divided as to be available for household purposes. I think Mr. Edison was the first, and not Mr. Swan, to produce a practically useful lamp on the incandescent principle with a filament of carbon in a vacuum. Mr. Edison's researches, too, in respect to the presence of occluded gases in metal and other substances, are exceedingly interesting and very sound and scientific in the manner he has carried them out. I think he rendered very great service not only to the future of electric lighting, but also to science by his investigations, and for this proper credit should be given him, more especially as in the future he will be able to show, and I have no doubt will show, that he was the first to succeed and I think it is as well to recognize it at once. I say this entirely disinterestedly, because it is very much to my disadvantage that Mr. Edison should be first, as I also have claims in this direction."

So much for the opinions of contemporary workers and what had been accomplished when Mr. Edison announced the birth of the commercially successful lamp on October 21, 1879.

Again we must call attention to the fact that what Mr. Edison presented at the time in the terse language of Judge Lacombe was "a burner of carbon, so small in cross-section that, by the ordinary usage of common speech, it may be fairly called a *filament;* the receiver which contains the burner is made *entirely* of glass; the conductors which connect with the burner pass through the glass; and from the receiver the air is exhausted."

He stated further in a famous court opinion:

"Prior to 1879 experimenters seemed to have reached the conclusion that success was to be attained, if at all, by modifications of the arc lamp, but up to that time no lamp, arc or incandescent, had been given to the public which, with the means then existing for generating and distributing the electric current, accomplished the result. After the date of the patent electric lighting by lights of moderate intensity became a commercial success. Subsequent improvements in the lamps and in other parts of the system have undoubtedly contributed materially to its development, but the record abundantly shows that, with lamps such as the patent described, constructed with the skill known to the art and operated under the conditions admitted by the generating and conducting apparatus then existing, it became practical for one generator to operate a considerable number of lamps, located at reasonable distances from it, and which at the same time were economical, durable and cheap enough to be commercially useful and so simple and reliable that they could be manipulated by the public. In view of the utter failure of the prior art to produce any such subdivision of the electric light, a lamp of this kind, which was capable of economical use in factories, large buildings and in smaller buildings should be considered commercially successful, though further development were needed to enable it to compete with gas for domestic lighting on even approximately equal terms."

It should be noted that in Mr. Edison's patent description he used the word "filament"—the first appearance in the art of that useful term. It would be interesting to present here some evidence to show that the filament of Mr. Edison was a structure more thread-like than any of his predecessors—a diameter of about 1/64 in.—whereas the prior art showed structures many times that size. So also the evidence that the resistance of Mr. Edison's filament was many times the resistance common to the prior art.

These factors so clearly defined by the learned Judge—a carbon filament of high resistance in an all-glass globe, conductors sealed into the glass, all enclosed in an exhausted glass globe, made a combination which spelled success, "long desired, sometimes sought, and never before attained" and this combination in the opinion of the court constituted a patentable invention.

Judge Wallace in a court decision rendered July 14, 1891, stated "It is impossible to resist the conclusion that the invention of the slender thread of carbon as a substitute for the burner previously employed, opened the path to the practical subdivision of the electric light."

Again, Judges Lacombe and Shipman stated in an opinion rendered October 4, 1892, "Edison's invention was practically made when he ascertained the theretofore unknown fact that carbon would stand a high temperature, even when very attenuated, if operated in a high vacuum, without the phenomenon of disintegration. This fact he utilized by the means he has described, a lamp having a filamentary carbon burner in a nearly perfect vacuum."

And, finally, Judge Colt on January 11, 1894, stated "Edison made an important invention, he produced the first *practical* incandescent electric lamp, the patent is a pioneer in the sense of the patent law, it may be said that this invention created the art of incandescent electric lighting."

These quotations from court opinions are presented not in the desire to emphasize the legal aspects of Mr. Edison's claims to priority of invention, but because their language is so direct and explicit that it would be difficult to convey the ideas expressed in them in clearer language.

An interesting story could be told of the search, covering every part of the globe, made to find the special type of bamboo, of the most uniform grade and containing a minimum of silicious matter, in order to furnish material for the bamboo filament which for a number of years was such a prominent feature of the Edison lamp and contributed in no small measure to its early success. The extraordinary uniformity and exactitude with which filaments in great numbers and of a given size could be pro-

duced from the bamboo fiber, both before and after carbonization, made it practicable, by assignment of different voltages to various central stations, to dispose of the entire factory product without recourse to the "flashing" process. The latter, an early development in the art, was applied only in the later years of the bamboo filament, and became again of great importance with the advent of the so-called "squirted" cellulose filament.

The extent to which auxiliary apparatus developed or improved by Mr. Edison was contributory to the successful solution of the problem, is illustrated by the notable improvements which he made in the apparatus for producing very high vacua, first by improvements in the means of obtaining the Torricellian vacuum and then by modification of the Geissler and Sprengel pumps, to which notable additions were applied, making it possible to obtain the highest vacua on the commercial scale that was necessary for exhausting incandescent lamp globes.

Such then was the Edison lamp—the keystone of the complete electric lighting system devised by him and worked out and developed along such permanently practical lines, forming the foundation of one of the most wonderful industrial developments the world has ever seen.

So much for the initial idea of the incandescent lamp itself. Let us again, quoting Mr. Edison, follow out in detail the development of his idea of a complete electric lighting system:

"A complete system of distribution for electricity had to be evolved, and as I had to compete with the gas system this must be commercially efficient and economical, and the network of conductors must be capable of being fed from many different points. A commercially sound network of distribution had to permit of being placed under or above ground and must be accessible at all points and be capable of being tapped anywhere.

"I had to devise a system of metering electricity in the same way as gas was metered, so that I could measure the amount of electricity used by each consumer. These meters must be accurate so that we could charge correctly for the current used, and also they must be cheap to make and easy to read and keep in working order.

"Means and ways had also to be devised for maintaining an even voltage everywhere on the system. The lamps nearest the dynamo had to receive the same current as the lamps farthest away. The burning out

or breaking of lamps must not affect those remaining in the circuit, and means had to be provided to prevent violent fluctuations of current.

"One of the largest problems of all was that I had to build dynamos more efficient and larger than any then made. Many electrical people stated that the *internal* resistance of the armature should be equal to the *external* resistance; but I made up my mind that I wanted to sell all the electricity I made and not waste half in the machine, so I made my internal resistance small and got out 90 per cent. of salable energy.

"Over and above all these things, many other devices had to be invented and perfected, such as devices to prevent excessive currents, proper switching gear, lamp holders, chandeliers, and all manner of details that were necessary to make a complete system of electric lighting that could compete, successfully, with the gas system. Such was the work to be done in the early part of 1878. The task was enormous, but we put our shoulders to the wheel, and in a year and a half we had a system of electric lighting that was a success. During this period, I had upwards of one hundred energetic men working hard on all the details.

"One question concerning this early system has often been asked, namely: 'Why did I fix 110 volts as a standard pressure for the carbon filament lamp?' The answer to this is that I based my judgment on the best I thought we could do in the matter of reducing the cost of copper and the difficulties we had in making filaments stable at high voltages. I thought that 110 volts would be sufficient to insure the commercial introduction of the system, and 110 volts is still the standard."

To have conceived and reduced to practical operative form the innumerable elements which constituted such a broadly conceived plan was indeed a colossal undertaking. From the time that Mr. Edison announced the consummation of his indefatigable labors, by the demonstration of a practical and commercially successful incandescent lamp, to the putting into operation of the Pearl Street Station in New York City, September 4, 1882, the public clamored for some tangible evidence of the arrival of the much heralded rival of gas, although hardly three years had elapsed—an absurdly short time for the carrying out of such a stupendous programme.

The intensity of application, indomitable perseverance, inventive and constructive resourcefulness, and joy in accomplishment, that were necessary to achieve such a result, it is difficult now to

appreciate. It was indeed a severe tax on the endurance of the human machine.

The old Pearl Street Station, the prototype of the modern central station for the generation and distribution of electricity for light and power purposes, started off with a load of 400 lamps supplying some 85 buildings wired for 2300 lamps, and it served them through a complete underground system having a total length of 18 miles of feeders and mains, distributing the current over an area of a square mile.

The Edison Central Station system was a practical working success at the very outset. Difficulties were encountered of course, unexpected, patience-trying contingencies and emergencies had to be met, but the system worked, it delivered satisfactory service and presently it showed also the beginnings of a sound commercial and financial success.

The inquiry has often been made as to what single element out of all this splendid aggregation of units, called the Edison System, can be considered to have been primarily the factor to which its success is attributable.

The keystone of it all can be said to be in the very early recognition by Mr. Edison of the practical importance of the "multiple arc principle." This fundamental idea is so important and its engineering application so broad, that a word or two of definition seems essential to a proper comprehension of Mr. Edison's scheme. The earlier conceptions of electric lamps, as exemplified in all the existing arc light systems and also in the experimental demonstrations, was that their mode of circuit connection, almost without exception, involved the use of the "series" system, the lamps being connected one after another—in series, as we say—like beads on a string and, therefore, not independent of one another, but all dependent on the integrity and continuity of the circuit or string.

At the very outset Mr. Edison proceeded along different lines—based on the important principle of his lamp with a filament of high resistance—providing for absolute independence not only of the individual lamp, but almost every other element of the system, from the boiler in the station to the interior wiring on the

consumer's premises—where the apparatus was mechanical, protecting it by stop valves, by-passes, or apparatus in duplicate, and where electrical, by providing alternate paths and parallel supply circuits, all constructively connected like the rungs of a ladder. In other words, the continuity of the system was not dependent on any single one of its elements, every feature was practically in duplicate, and means were provided so that any defective section could be instantly segrated and eliminated, where practicable, automatically.

This principle of operating everything in "multiple arc," an efficient method of duplicating everything, is the principal essential to regularity and continuity of electric service of the highest standard and this has always been a conspicuous outstanding feature of the Edison system where it has been properly installed and operated.

This principle was not essentially new, as it is also one of the characteristic features of the modern system for the manufacture and distribution of illuminating gas, and Mr. Edison in adopting it for its electrical analogue showed a keen appreciation of its practical utility and of its demonstrated value.

Many of the important elements of the system might warrant a more detailed reference, such as the beautiful—for it is more than merely ingenious—conception underlying the feeder and main system and its inter-connections, the interesting types of switches that were developed to meet new needs as they arose, from the giant instantaneous knife switches of the Jumbo machines to the lamp socket switches, wiring and distributing devices, and many other constituents of the system, all of which have served as prototypes for the best modern devices in use to-day.

It would lead us too far afield to review the numberless inventions which followed the Edison lamp in such rapid succession and which, as an official said, "kept hot the path to the Patent Office," but it may be interesting to note the immense number of these with which Mr. Edison is credited—over 100 patents covering phonographs, 20 on storage batteries, 20 on meters, 147 on the telegraph, 32 on the telephone, 169 on electric lights, and 53 on ore milling machinery.

Did time and the occasion permit, it would be interesting to

consider in detail Mr. Edison's work in the development of the dynamo-electric machine, the electric meter, the underground distributing system, and the numberless devices designed for use in conjunction therewith. The latest patent relating to this line of work, showing how constantly it has occupied Mr. Edison's interest, even in the midst of the press in later years of pioneer work in divergent fields, is indicated by the fact that his latest patent covering a filament for incandescent lamps, bears the date of March 29, 1898.

I desire to say a word here in regard to Mr. Edison's work in another field, that of chemistry, involving, if I may be permitted to refer to it, a personal reminiscence. Some years ago I had the great honor of accompanying Lord and Lady Kelvin, both ardent admirers of Mr. and Mrs. Edison, on a visit to their laboratory and home at Orange, N. J. Lord Kelvin it will be remembered was not only a warm friend of Mr. Edison but one of his most enthusiastic supporters. Mr. Edison after explaining to Lord Kelvin some details of his nickel-iron storage battery, entered into a very warm discussion with him as to the stability of some of the higher oxides of nickel, a field in which Lord Kelvin had done much research work. Later at Mr. Edison's home the visitors were shown an elaborate investigation that was being conducted there, Mrs. Edison being an interested participator and *keeper of the records,* covering the crystallization of metallic salts under the influence of a magnetic field.

In the train on the return to New York, Lord Kelvin expressed the view that the visit had revealed an entirely new, and to him hitherto unappreciated side of Mr. Edison's genius—his intimate knowledge of theoretical and applied chemistry, justifying him in expressing the opinion that he considered Mr. Edison to be one of the great industrial chemists of the time.

The personality of Mr. Edison has many points in common with that master mind of the Middle Ages and of all times, Leonardo da Vinci. They are strikingly similar in their keenness of observation, inventive capacity, mechanical genius and thirst for knowledge—amounting almost to an obsession—a desire to investigate and wrest from nature her secrets by experimental processes. As Leonardo says in his famous note-books:

"Before deducing a general rule from the specific case, try the experiment two or three times and observe if the experiments always give the same results."

"If you want to make simple castings quickly, make them in a box of river sand, wetted with vinegar."

"Try if the *hot* iron will attract iron filings."

"To-morrow I will have a new type of whip made and will try it."

"The thickness of the muzzle of small guns should be from ½ to ⅓ of the diameter of the ball and the length from 30 to 36 balls."

Let us compare this with a few characteristic excerpts from Mr. Edison's so-called "Notion Books."

"Experiment with the instantaneous formation of metallic tin-flake by chemical composition in glass and on paper to form metallic dots and dashes in paper for repeating."

"Chloroform is a test for iodine."

"Experiment on the speed, strength of current and form of coil which is best to work by induction. It may be a primary of 20,000 ohms resistance and a secondary of 10,000 ohms will work with very delicate current."

"This is a great discovery for electric light in the way of economy."

But here the comparison ends, as Leonardo was also an accomplished courtier, a musician, a poet and an artist in the broad Renaissance sense of the term, a carver, sculptor and painter.

It is the common belief that Mr. Edison is altogether empirical in his methods, a despiser of precedent along paths previously followed and a lucky though haphazard experimenter in opening new ones, but this altogether needs qualification if not restatement.

Before launching into a new line of investigation he carefully considers what may be learned from past experience and what others have done along similar lines, although he does not then blindly follow their lead, but with original thought and un-

trammeled by precedent he seeks to open up new possibilities by research and he does not shrink from exploring the most unpromising paths and put to test the most paradoxical alternatives. His splendid library compassing the best there is in the scientific literature of all languages is put under tribute and the assistance of men with scientific training and experience in research is enlisted and consulted.

While we are conveying this tribute to our honored guest I am sure he would feel displeased if we failed to mention the important part, in achieving his wonderful success, played by the zealous and enthusiastic galaxy of personal associates and assistants whose loyal co-operation Mr. Edison enjoyed and the support he received from the host of expert specialists and skilled mechanics who constituted the working forces which knew so well how to put his ideas into practical commercial form.

And here let us refer in passing to a foible which is largely responsible for a misconception in regard to Mr. Edison, assigning to him an excessive desire for newspaper notoriety. As a matter of fact the extreme good nature of our subject, his desire to help the "boys" of the press, and his readiness to be interviewed by them, often results in "copy," which is afterwards colored by their own perfervid imagination and in which scientific accuracy of statement is not always conspicuous. Let me read the text of a letter from Mr. Edison written to a New York paper on this subject in 1898:

"Sir: I wish to protest through *The Sun* against the many articles appearing in the sensational papers of New York from time to time, purporting to be interviews with me about wonderful inventions and discoveries made or to be made by myself. Scarcely a single one is authentic, and the statements purporting to be made by me are the inventions of the reporter. The public are led from these articles to draw conclusions just the opposite of the facts. I have never made it a practice to work on any line not purely practical and useful ,and I especially desire it to be known, if you will permit me, that I have nothing to do with an article advertised to appear in one of the papers about Mars."

T. A. Edison.

Mr. Edison is an indefatigable worker, with the imagination of a poet, preaching the gospel of the joy of work, a man of the

simplest tastes, an untiring searcher after truth, an altogether charming personality, patient, affable, always optimistic.

We are, therefore, delighted to honor Thomas Alva Edison to-night, not only as a great scientist and one of the greatest inventive geniuses of all time, but as a modest, unspoiled and unassuming man, with broad sympathies for all sorts and conditions of men; the greatest living American, a great benefactor of the human race!

Mr. President, I have the distinguished honor of presenting Mr. Thomas Alva Edison, Doctor of Science Princeton University, honored by many foreign sovereigns and governments with their highest civil decorations, distinguished by numerous national and foreign scientific societies and academies with their honorary memberships and medals. And now on behalf of the Illuminating Engineering Society I ask that you bestow upon him its honorary membership.

ACCEPTANCE OF HONORARY MEMBERSHIP FOR THOMAS ALVA EDISON.*

BY WM. H. MEADOWCROFT.

Mr. President, members of the Illuminating Engineering Society, ladies and gentlemen: The duty assigned to me is a pleasant and honorable one, and one that I hope to discharge in a manner befitting the representative, for the moment, of a man whose native characteristics are simplicity and modesty.

In the first place, Mr. Edison wishes me to extend to you, the officers and members of the Illuminating Engineering Society, his most cordial greetings and to congratulate you upon the eminent position to which your Society has so meritoriously attained.

It is a long cry back to the old days of historic 65 Fifth Avenue, when we were struggling to establish a lighting system and wrestling with many knotty problems, then novel, but now relegated to the a b c class. The broad conception of illuminating engineering had not yet been developed in the 80's, for our energies were largely employed in problems of manufacturing, selling and installing lighting plants. Even in these lines we had our troubles occasionally. I remember on one occasion the late C. E. Chinnock berating one of our engineers who had installed a plant and evidently had not done it very well, for Mr. Chinnock said, "Here we are, trying to sell plants for Mr. Edison, and you come away from an installation leaving some glass globes containing red hot hairpins gasping for volts!"

I must not indulge in reminiscences, however, but attend at once to my business here, which is to express Mr. Edison's deep appreciation of the honor you have conferred upon him in electing him an Honorary Member of your Society. He esteems it to be indeed a privilege to occupy the place your courtesy has extended to him, as the aim and work of the Illuminating Engineering Society is directed to the highest and most efficient use of natural and artificial light, with the object of raising the standard of human efficiency in commercial and social life.

In Mr. Edison's name I thank you.

* This acceptance for Mr. Edison was given upon presentation of honorary membership at the mid-winter convention of the Illuminating Engineering Society, New York, February 10, 11, 1916.

EDISON: THE GENIUS.*

BY CHARLES P. STEINMETZ.

In celebrating the tenth anniversary of the Illuminating Engineering Society, we are honored to-night by the presence of the man who has done more than anybody else to make possible the art and science of illuminating engineering.

When our ancestor, the primordial ape, first discovered and used fire, and thereby became man, illuminating engineering was born, and progressed from the camp-fire and the torch, to the candle, the oil lamp and kerosene lamp, until finally in gas—now the only competitor of electricity—an efficiency was reached making general illumination possible, such as the lighting of streets in cities.

But all these illuminants, including even the arc lamp, can be used only in one position, usually the upright one, and require free space above for the escape of heat and gases, and thus can not be located at or near the ceiling where the lamps properly belong, for in nature, all light comes from above—as from the sun and the moon.

It was Edison who gave us the incandescent lamp, the only illuminant which can be placed in any position, upside down or right side up, located at the ceiling or in corners or anywhere, in short, which possesses the complete flexibility in location and in sizes, and which made illuminating engineering possible by giving the engineer unrestricted control of the location of the lamps. Therefore, I say to you, it was Edison who created modern illumination, who made it possible to convert night into day and extend the hours of daylight, by giving us the incandescent lamp.

This is an age of intellectual giants who have created modern civilization almost within one generation. Still within the memory of our generation the steamship, the locomotive and the telegraph were recent discoveries; as were also the telephone, electric lamps, electric motor, the conquest of the air and of the wireless ether.

* This eulogy was delivered at the mid-winter convention of the Illuminating Engineering Society, New York, February 10, 11, 1916.

The Illuminating Engineering Society is not responsible for the statements or opinions advanced by contributors.

Within one generation man has annihilated the limitation of time and space: we have seen the telephone carry the human voice across city and country, and now we talk over the copper wire across continents, where at the beginning of our generation no road or even a trail led through the wilderness.

From waterfall and steam turbine station, electricity brings us the power to do the world's work, in home and industry, and to merge night into day.

The trolley car is revolutionizing social conditions, by bringing the advantages of the city to the country dweller and opening the country as a place of residence to the city worker.

The air has been conquered, and higher than the eagle, faster than the albatross and more enduring than the carrier pigeon, the aeroplane and the dirigible carries man.

There is no place on earth, whether on the storm tossed ocean or the Arctic ice or in the beleaguered fortress, whence lightning does not carry the wireless message across space.

We are studying the chemistry of worlds, which even light, traveling hundred thousands of miles in a second, requires centuries to reach; and we observe objects so small that the most powerful microscope fails to show them.

In the wireless telephone, we have thrown the human voice through empty space across oceans and continents, and in the phonograph have flung the voice of man across the ages of time, so that still unborn generations will hear the word and counsel, and will listen to the living voice of the generations of the past.

It is with the greatest pleasure that I greet in our midst, as an Honorary Member of our Society, the greatest of the giants, who have made the modern World, the genius Edison.

THE SCOPE OF ILLUMINATING ENGINEERING.*

BY CHARLES P. STEINMETZ.

Synopsis: This paper defines the term "illuminating engineering." The phenomena and effects of light in producing effective illumination are outlined from the viewpoint of the illuminating engineer, the physiologist, the psychologist and the ophthalmologist. Brief mention is made and examples given of the effect on the eye due to directed, diffused and colored light.

Ten years ago the Illuminating Engineering Society was founded. Five years ago illuminating engineering was established as a recognized branch of engineering, through a course of lectures, given by the Illuminating Engineering Society jointly with the Johns Hopkins University. In the fall of the present year another lecture course will be given by the Illuminating Engineering Society jointly with the University of Pennsylvania, covering and bringing up to date the entire field of illuminating engineering.

While illuminating engineering probably is the youngest recognized branch of engineering, it is not engineering merely in the narrow sense of electrical and mechanical engineering—the application of the laws of nature to the service of man—but its scope is far broader. It represents a problem in the application of physics, that is, engineering, to the design and construction of a lighting installation. But the product of the installation is light, and light is the physiological effect of radiation on the human eye, and the efficiency of the illumination thus comes into the realm of physiology as well as engineering. The psychological effect of the physiological phenomenon of light is what very largely determines the satisfaction of an illumination, and thus the psychologist becomes interested. The success of an illumination depends not merely on the location and size of the light sources, but equally on the architectural structure of the building, on the decoration of the walls and ceilings, etc., and hence the architect's and the decorator's work is of importance

* An address presented at the mid-winter convention of the Illuminating Engineering Society, New York, February 10, 11, 1916.

in the success of illumination. The abuse of light, the defects of illumination, become of interest to the ophthalmologist. Light, especially certain forms of it, exerts a powerful effect on living tissue, and thereby becomes of value in sanitation, in medicine and therapeutics.

It is seen, therefore, that illuminating engineering embraces the sciences of physics, physiology and psychology, architecture, decoration, ophthalmology, hygiene, bacteriology and therapeutics, and our Society is of importance to the physicist and engineer, the physiologist and the psychologist, to the architect and the decorator, to the ophthalmologist, the sanitarian and the physician. The design of a successful illumination begins with the plans of the architect, and ends with the consideration of the occupation and the temperament of the user of the light.

It is a problem of engineering to determine the amount of light required for the different purposes of a business street or a suburban street, a theatre or a school room, an office or a private dwelling house. But this does not yet make the success of the illumination: one may use a few large units of light, and in some places get insufficient light, in others excessive light traversed by black shadows. Such unsatisfactory results are seen in many street illuminations. Or he may go to the other extreme, and by the use of numerous small lamps, or by hiding the lamps and using their reflected light, get high uniformity, and yet the illumination becomes dull and the seeing poor because of lack of contrast. Good seeing thus requires the avoidance of excessive contrasts, but also the avoidance of absolute uniformity. It requires a certain amount of properly directed light, to give the contrast of shadows and background, but also diffused light, that is, light coming in all directions, like the daylight on a cloudy day, not to have the shadows too dense.

The eye is not a physical instrument, its scale is the logarithmic scale, and not the algebraic scale of most physical instruments; it is affected by higher illumination of surrounding objects—as glare—by the duration of its use, manifested in fatigue, etc. Hence there arises the porblem of avoiding glare to limit the location and character of the illuminants, by relegating them out of the field of vision, or restricting their intrinsic brilliancy—by diffusion globes, etc. The study of the problem of reducing fatigue

becomes an extensive one: fatigue to a large extent depends on the use of illumination. An illumination which is least fatiguing for one purpose may become most fatiguing for another. This also involves the color of the light. Thus a color of light which accentuates slight differences in certain color shades, would reduce fatigue where the distinction of these differences is of importance, and yet would increase the fatigue where these distinctions are immaterial. This effect is marked, for instance, between the yellow incandescent and the green mercury light.

Custom and association exert dominating psychological influences. Thus the corpse-like appearance under the mercury light condemns its use in the ballroom, while the higher acuity of vision recommends it for other uses. The harsh appearance under white light gives a preference to yellow light where the appearance of human faces is of interest. The "warm yellow light" may be preferable to the "cold white light" for the dweller in the northern temperature zone, while the "cool white light" may appear preferable to the "hot yellow light" for the desert dweller.

The further the design of a satisfactory illumination leads us from applied physics into physiology and psychology, the more naturally the human element dominates, and the more the success of the illumination depends not alone on light flux and its distribution, but largely on the condition of the human being using the illumination.

It is only in our generation that light production has reached an efficiency making artificial illumination universally available for industrial and other work, and thereby extending the hours of daylight. With this extension of the day by artificial illumination, the art and science of illuminating engineering becomes of fundamental importance to the human race. It is true that through ages lighting equipments have been installed without illuminating engineering, and that even to-day most illuminating installations are not properly designed, but have just "happened." But it is also true that working under artificial illumination is recognized as putting a far more severe strain on the eyes than daylight work, and that the number and gravity of eye troubles is increasing. Only to a limited extent is this due to the abuse of

the eye made possible by artificial illumination by using the eye for too long a period during the day. Mainly it is the result of the unsatisfactory character of many artificial illuminations. There is no reason why a good and properly designed artificial illumination should place any greater strain on the eyes than an equally good daylight illumination. Here then is a field in which the ophthalmologist is interested.

Direct sunlight, and especially ultra-violet light, is one of the most powerful germ killers, and it is becoming recognized as of increasing importance as a disinfectant and sterilizing agent. However it destroys not only micro organisms, but also the living tissue of animals and of man. Ultra-violet light, especially that further away from the visible violet, is very harmful to the eye, and may even produce blindness. Fortunately, it is absent from the light of common illuminants, and glass is opaque to it—it does not let it pass but absorbs it. Human tissue is more resistant to ultra-violet light than germs are, and germ diseases of the skin (tuberculosis) can be and are frequently cured by ultra-violet light, while deeper seated ills are reached by that extreme ultra-violet light, the X-ray, which penetrates opaque bodies. The therapeutic value of the ultra-violet light and X-rays resides in the difference between the higher resistance of the normal human tissue and the lesser resistance of the germs or the diseased tissue which gives the curative effect, and, therefore this subject, which is of great interest and importance to the physician, is an unsafe one for the layman to handle.

ILLUMINATION OF THE PANAMA-PACIFIC INTERNATIONAL EXPOSITION.*

BY WALTER D'ARCY RYAN.

Synopsis: The illumination of the Panama-Pacific Exposition marked the turning point from bizarre pageant illumination to the radiant grandeur and beauty of flood lighting from concealed sources. The author tells of the preliminary steps involved in the design of the installation and describes the organization of the forces in charge of the work. Details of the use of electricity and gas in some of the more important sections of the exposition is given. Many new devices were developed especially for this pageant; smoke-clouds illuminated by searchlights, flood lights, fountains and illuminated jewels in intricate combination, formed the basis of the illumination. A number of colored plates illustrates a few of the effects obtained.

The illumination of the Panama-Pacific International Exposition was a development made possible by the science of lighting which had grown up under the name of "illuminating engineering." The possibility of developing a scientific branch of lighting to be known as illuminating engineering made itself apparent during the development of the Elihu Thomson arc lamps of 1893, which in various plain and ornamental forms were designed for alternating and direct-current series and multiple circuits. These were soon followed by the so-called enclosed arc lamps, which further suggested the necessity of a careful scientific study in the selection, location, reflectoring and globing of the various units, to obtain maximum results at minimum cost for the lighting industrial establishments, stores, streets and other purposes.

While the author personally assumed the title of "illuminating engineer," it could not be officially recognized at that time, but the work then started, formed the nucleus of the new science to be developed. A few years later a circular letter, officially recognizing the title "illuminating engineer," was issued by the General Electric Company. In the meantime, new photometers, luximeters and luminometers were built for laboratory and field work.

* An address delivered at the mid-winter convention of the Illuminating Engineering Society, New York, February 10, 11, 1916.

Lumichromoscopes and parachromoscopes were designed for studying the effects of different lights on colored materials. Adjustable and concentric diffusers were created, scientific glassware and reflectors of various types made their appearance, and extensive laboratory and field tests were conducted, scientific data compiled, and development became general in the application of both arc and incandescent lamps. Supplementing the engineering work, papers were read at conventions, colleges and elsewhere, to create an interest in the importance of the development. Mr. George H. Stickney rendered very valuable assistance in this connection.

In addition to the excellent work being carried on by commercial testing laboratories and reflector laboratories, many contemporary contributors broadened the field. Scientific journals gave considerable space to the subject, and periodicals devoting their entire space to illuminating engineering were published in this country and abroad. An Illuminating Engineering Society was formed in the United States, and this action was quickly followed in England. The membership in each case was made up of engineers, lighting specialists, architects, decorators, oculists, glass manufacturers, fixture designers, psychologists, photometrists and representatives of many other sciences and industries. Valuable contributions were received from various sources, and further interest was stimulated thereby.

To-day in many cities proficient illuminating engineers are doing excellent work and practically every large manufacturer of lighting units or appurtenances has either an illuminating engineering department or an associated illuminating engineer.

In lighting propositions involving special effects or treatment, it has become the practice to employ an illuminating engineer in addition to the electrical engineer. It was therefore natural that when the Panama-Pacific International Exposition decided that its illumination should, if possible, possess features of novelty to correspond with its general policy, it recognized the necessity of establishing a department of illuminating engineering in addition to the electrical and mechanical department which was under the direction of Mr. G. L. Bayley.

The subject of lighting was taken up with the Exposition of-

ficials and the Architectural Commission, in August of 1912. Three months later a scheme was presented, and for the first time in history the lighting of an International Exposition was completely designed and charted before the buildings were erected. This included not only the general, utilitarian and spectacular lighting, but also the design of lighting standards, fixtures and heraldic banners, with suggestions for the texture of the buildings to obtain the best light effects, and specifications covering the glassware to be used with the various lighting units, as well as glass for the glazing of the buildings. The general results obtained were due in a great measure to the co-operation of the chiefs of all departments, architects, designers, sculptors, modelers, horticulturists and many others.

As a contribution to the Exposition, the General Electric Company established a branch of its Illuminating Engineering Laboratory on the grounds. In addition to the author, the local organization consisted of A. F. Dickerson, first assistant; J. W. Gosling, decorative designer; J. W. Shaffer, chief draftsman; F. F. Schilling, photographer; H. E. Mahan and F. A. Benford, illuminating engineers, and E. J. Edwards, illuminating engineer, representing the laboratory of the National Lamp Works at Cleveland. This field organization was supported by assistance from the various laboratories of the company at Cleveland, Harrison, Lynn, and at Schenectady, where, under the direction of Major R. H. Ryan, tests were run on luminous arc lamps, incandescent electric lamps, "gas arc lamps," searchlights, glassware, and various other devices and materials entering into the illuminating effects.

A detailed description of the lighting in a limited space is, of course, impossible. It is the purpose of this description to convey a general idea of the effects rather than the means employed to produce them.

The illumination of the Exposition marked an epoch in the science of lighting and the art of illumination. Like many other features of the Exposition, the illumination was highly educational in character, and emphasized more than anything that had gone before, the result of a concentrated study in the best uses and applications of artificial light.

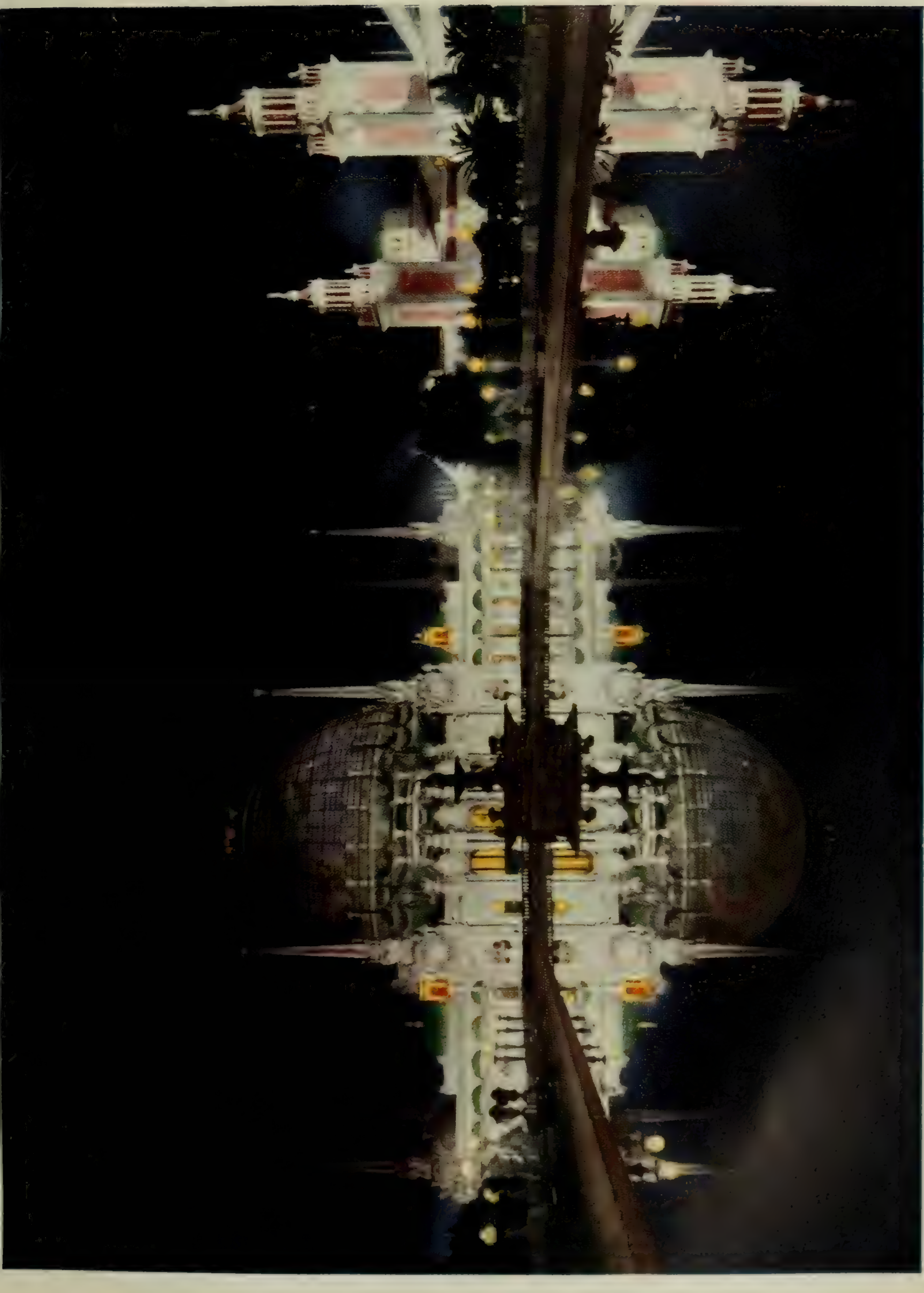
The buildings of previous expositions had in the main been

used as a background upon which to display lamps. The art of incandescent outlining, as exemplified by the beautiful effects obtained at the Pan-American Exposition at Buffalo, could probably not be improved upon, and furthermore, this form of illumination had been extended to amusement parks throughout the world and had become commonplace. Its principal disadvantages were the diminution of artistic effectiveness at close range, similarity in effects from different view points, the suppression or complete obliteration of architectural features and the economic necessity of extensive untreated surfaces. Furthermore, the glare from so many exposed sources when assembled on white or light colored buildings, caused severe eye and nerve strain.

The lighting scheme and scope of the Panama-Pacific International Exposition called for a radical departure from previous practice. Incandescent lamp outlining on the main group of palaces was avoided, and screened or masked flood and relief lighting to produce the third dimension or depth, substituted. Great care was exercised to preserve the architectural features and color, with proper relative intensities. For the first time at an international exposition, the illuminating sources, as such, whether arc, incandescent or gas lamps, lost their identity. While a uniform system was maintained throughout, each court possessed its individual characteristics with radical differences, and at the same time the transition from one effect to another was harmonious even to the extent of an intermediate step or carnival effect on the "Avenue of Progress" connecting the "Zone" and the main group of "Palaces."

During the pre-exposition period, there were many who maintained that the general public would not be attracted except by the glare of exposed brilliant light sources. The lighting of the exposition, however, immediately disproved this theory and a strong psychological appeal was made by the highly artistic lighting effects.

During the period elapsing between the Louisiana Purchase Exposition and the Panama-Pacific International Exposition, wonderful advances had been made in the efficiencies of all types of lighting units. Thus it was possible to illuminate in the main group of buildings and grounds, approximately 8,000,000 sq. ft.



of horizontal and vertical surfaces with intensities ranging from 0.1 to 0.25 of a foot-candle in the incidental gardens and roadways, from 0.25 to 3 foot-candles on the building facades and adjacent lawns and gardens, and from 5 to 15 foot-candles on the towers, flags and sculptural groups. The lighting load on the main group of buildings, including the window lighting and the scintillator, was approximately 5,000 kw. The total connected load for all purposes, including the "Zone," foreign and state sections and exhibitors, for lighting, incidental heating, motor, and other service was 13,954 kw. with a maximum peak of 8,200 kw. and an average peak of 7,880 kw.

While the lighting of the Exposition was primarily electric, all modern light sources of intrinsic merit were used, and a number of excellent gas features were introduced. About four miles of streets in the foreign and state sections were illuminated with high-pressure "gas arc lamps," equipped with 20-in. opal globes mounted with their centers about 16 ft. above the roadways on ornamental poles spaced approximately 100 ft. apart, staggered. The same type of lamp was used for emergency lighting on the kiosks throughout the grounds. Five-mantle gas arc lamps enclosed with ornamental lanterns were used in pairs on the standards in the "Zone" section and the same type of lamp, in smaller sizes, furnished emergency lighting at the gates and important exits from the main group of buildings. Gas flambeaux were introduced in the effects in the "Court of Abundance" and the "North Approach." The total gas flow for the purposes mentioned was approximately 15,000 cu. ft. per hour.

Furnishing wonderful contrast to the soft illumination of the palaces, with their high lights and shadows, was the "Zone," or amusement section, with all the glare of the bizarre, giving the visitor an opportunity to contrast the light of the past with the illumination of the future. As we passed from the "Zone" with its blaze of light, we entered a pleasing field of enticement or carnival spirit. We were first impressed with the beautiful colors of the heraldic shields, on which were written the early history of the Pacific Ocean and California. Behind these banners were luminous arc lamps in clusters of two, three, five, seven and nine, ranging in height from 25 to 55 ft. We looked from

the semi-shadow upon beautiful vistas and the Guerin colors, which fascinating in the daytime, were even more entrancing by night. The lawns and shrubbery surrounding the buildings and the trees with their wonderful shadows appeared in magnificent relief against the soft background of the palaces. The "Tower of Jewels," with its 102,000 "Novagems," (which suggested the official title "Jewel City") standing mysteriously against the starry blue-black of the night, might be said to have surpassed the dreams of Aladdin.

As we passed through the approach to the "Court of Abundance" from the east, with its masked shell standards strongly illuminating the cornice lines and gradually fading to twilight in the foreground, and entered the Court, we were impressed with the feeling of mystery analogous to the prime conception of the architect's wonderful creation. Soft radiant energy was everywhere; lights and shadows abounded, fire hissed from the mouths of serpents into the flaming gas caldrons and sent its flickering rays over the composite Spanish-Gothic-Oriental grandeur. Mysterious vapors rose from steam-electric caldrons and also from the beautiful fountain group symbolizing the earth in formation. The cloister lanterns and the snow-crystal standards gave a warm amber glow to the whole Court, and the organ tower was illuminated in the same tone by colored searchlight rays.

Passing through the "Venetian Court," we entered the "Court of the Universe," where the illumination reached a climax in dignity thoroughly in keeping with the grandeur of the Court. Here an area of nearly half a million square feet of horizontal and vertical surface was illuminated by two fountains rising 95 ft. above the level of the sunken gardens, one symbolizing the rising sun and the other the setting sun.

The shaft and ball surmounting each fountain was glazed in heavy opal glass, which was coated on the outside in imitation of travertine marble, so that by day they did not in any sense suggest the idea of light sources. High efficiency incandescent electric lamps installed in these two columns gave a combined initial (bare lamp) candlepower of approximately 500,000 and yet the intrinsic brilliancy was so low that the fountains were free

from disagreeable glare and the great colonnades were bathed in a soft radiance. For relief lighting three incandescent lamps were placed in specially designed cup reflectors located in the central flute to the rear of each column. This brought out the Pompeiian red walls and the cerulean blue ceilings with their golden stars, and at the same time the sources were so thoroughly concealed that their location could not be detected from any point in the court.

The perimeter of the sunken gardens was marked by balustrade standards of unique design consisting of Atlantes supporting urns in which were placed incandescent lamps of relatively low candle-power. The function of these lamps was purely decorative.

The great arches were carried by concealed lamps, red on one side and pale yellow on the other, thereby preserving the curvature and the relief of the surface decorations. The balustrade of this court, 70 ft. above the "Sunken Gardens," was surmounted by ninety seraphic figures with jeweled heads. These were cross lighted by 180 incandescent searchlights, the demarcation of the beams being blended out by the light from the fountains of the "Rising Sun" and "Setting Sun."

Passing through the "Venetian Court" to the West, we entered the "Court of the Four Seasons," classically grand. We were then in a field of illumination in perfect harmony with the surroundings, suggesting peace and quiet. The high current luminous arc lamps mounted in pairs on 25-ft. standards masked by Greek banners were wonderfully pleasing in this setting. The white light on the columns caused them to stand out in semi-silhouette against the warmly illuminated niches with their cascades of falling water, and the placid central pool reflected in marvelous beauty, scenes of enchantment.

Having reviewed in order illuminations mysterious, grand and peaceful, we emerged from the west court upon lighting classical and sublime, the magnificent "Palace of Fine Arts" bathed in what might be called "triple moonlight," casting reflections in the lagoon impossible to describe. The effect was produced by searchlights on the roofs of the "Palace of Food Products" and "Palace of Education" supplemented by concealed lighting in the rear cornice soffits of the colonnade.

Having passed through the central, east and west axis of the Exposition, there were many more marvels to be seen. If one had wished to study the art of illumination he could have visited the Exposition every evening throughout the year and still found detail studies of interest. For instance, he could have seen artificial illumination in competition with daylight. On certain occasions the projectors flood lighted the towers before the sun went down. If one were fortunate enough to have been present in the northwest section of the "Court of the Universe" and watched the marvelous effect of the "Tower of Jewels" as the daylight vanished and the artificial illumination rose above the deepening shadows of the night, he saw the prismatic colors of the jewels intensify and the "Tower" itself become a vision of beauty never to be forgotten.

The "South Garden" could very properly have been called the "Fairyland of the Exposition" at night. When light was first turned on, the five great towers were bathed in ruby tones and they appeared with the iridescence of red hot metal. This gradually faded to delicate rose as the flood light from the arc projectors converted the exterior of the towers into soft Italian marble. The combination of the light from the projector arc lamps (white) and that from the concealed incandescent lamps (ruby) produced shadows of a wonderful quality. Each flag along the parapet walls had its individual projector which converted it into a veritable sheet of flame.

As a primary line of color the heraldic shields and cartouche lamp standards produced a wonderful effect against the travertine walls bathed in soft radiance from the luminous arc lamps, which also brought out the color of the flowers and lawns and created pleasing shadows in the palms and other tropical foliage. This was supported by a secondary effect in the decorative incandescent electric standards along the "Avenue of Palms" and throughout the gardens. A finishing touch was added by the effect of "life within" created by the warm orange light emanating from all the Exposition windows supported by rose red light in the towers, minarets, and pylon lanterns.

To the west the enormous glass dome of the "Palace of Horticulture" was converted into an astronomical sphere with its re-

volving spots, rings and comets appearing and disappearing at the horizon and changing colors as they swung through their orbits. The action was not mechanical, but astronomical.

To the East the "Festival Hall" was flood lighted by luminous arc lamps and accentuated by orange and rose light from the corner pavilions, windows, and lanterns surmounting the dome. This was all reflected in the adjacent lagoon and possessed a distinctive charm which will long remain in the memory.

Purely spectacular effects were confined to the scintillator at the entrance of the yacht harbor. This consisted of forty-eight 36-in. projectors having a combined projected candlepower of over 2,600,000,000. This battery was manned by a detachment of U. S. Marines.

A modern express locomotive with 81-in. drivers was used to furnish steam for the various fireless fireworks effects known as "fairy feathers," "sunburst," "chromatic wheels," "plumes of paradise," "devil's fan," etc. The locomotive was so arranged that the wheels could be driven at a speed of fifty or sixty miles per hour under brake, thereby giving forth great volumes of steam and smoke, which, when illuminated with various colors, produced a wonderful spectacle.

The aurora borealis created by the searchlights reached from the Golden Gate to Sausalito and extended for miles in every direction. The production of "Scotch plaids" in the sky and the "birth of color," the weird "ghost dance," "fighting serpents," the "spook's parade," and many other effects were fascinating.

Additional features consisted of ground mines, salvos of shells producing flags of all nations, grotesque figures and artificial clouds for the purpose of creating midnight sunsets.

Over 300 scintillator effects had been worked out and this feature of the illumination was subject to wide variation. Atmospheric conditions had a great influence upon the general lighting effects, for instance, on still nights the reflections in the lagoons reached a climax, particularly the "Palace of Fine Arts" as viewed from "Administration Avenue"; the facades of the "Palace of Education" and "Palace of Food Products" as seen in the waters through the colonnade of the "Palace of Fine Arts"; the "Palace of Horticulture" and "Festival Hall" from their re-

spective lagoons in the "South Garden"; the colonnades and the Novagems on the heads of the seraphic figures and the "Tower of Jewels" as reflected in the water mirror located in the north arm of the "Court of the Universe."

On windy nights the flags and jewels were seen at their best. On foggy nights there were produced over the Exposition wonderful beam effects impossible at other times.

When the wind was blowing from the land the scintillator display was different from nights when the wind was blowing from the bay. A further variety was introduced in the action of the smoke and steam on calm nights.

On the evening of St. Patrick's day all the searchlights were screened with green, and not only the towers but every flag in the Exposition took a new aspect.

Orange in various shades was the prevailing color for the evening of "Orange Day," and on the ninth anniversary of the burning of San Francisco, the Exposition was bathed in red, with a strikingly realistic demonstration of the burning of the "Tower of Jewels."

Never before was there such fiexibility on so large a scale, making it possible at very small expense and on short notice to introduce modifications in the illuminating effects. This was made feasible by use of the great number of searchlights, which on ordinary occasions projected white light, but by the introduction of screens the coloring could be completely changed.

Briefly, the lighting consisted, primarily of direct, masked, concealed, and projected effects, created by an harmonious blending of luminous arc lamps, searchlights, incandescent electric and gas lamps.

The high-current luminous arc lamp was selected for general flood lighting of the façades, lawns, and shrubbery on account of its white quality, high efficiency, and relatively low maintenance cost where great quantities of light are required.

The searchlights were used for illuminating towers and minarets, flags and other features where concentration was necessary.

High efficiency electric incandescent lamps in all sizes from 10 to 1,500 watts were employed generally throughout the Ex-

PERISTYLE, PALACE OF FINE ARTS, SOUTH WING

A remarkable night picture

spective lagoons in the "South Gardens"; the colonnades and the Novagems on the heads of the seraphic figures and the "Tower of Jewels" as reflected in the water mirror located in the north arm of the "Court of the Universe."

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The searchlights were used for illuminating [illegible] arets, flags and other features where concentration [illegible]

High efficiency electric incandescent lamps [illegible] 10 to 1,500 watts were employed generally [illegible]

position, especially where space was limited, warm tones were required and flexibility was of fundamental importance.

High-pressure gas lighting played an important part in street lighting in the Foreign and State sections; as did also low-pressure gas for emergency purposes and gas flambeaux for special effects.

PSYCHOLOGY AND LIGHT.*

BY HUGO MUENSTERBERG.

Synopsis: This address deals with the effects of light on mental functions. The author calls attention to the fact that quickness of reaction time and reaction under various sound stimuli is a function of the illumination. This is illustrated by descriptions of several interesting researches. The rhythm of alternation of intensity of light was shown to have marked influence on the mental powers. An interesting series of stimuli tests with railway light signals is described.

I am fully conscious how very little we psychologists can contribute to-day to your important discussions and how great the honor is if a psychologist is called at all to mingle in your council. Only reluctantly does the laboratory psychologist venture to express opinions where experienced men of affairs deliberate upon the needs of the community. Yet he is encouraged by the rapid progress which applied psychology has undoubtedly made in the last few years. You all know that psychology in our present sense of the word, a study of the mind with the means of an exact science, with laboratory experiments and in intimate contact with the physiology of the brain and the nervous system is a thoroughly modern science. The first regular workshop for experimental psychological research was not founded until 1878 in Leipzig. To-day a hundred such laboratories exist in this country alone. But while the advance has been rapid and while ever new fields of mental life have been conquered by the scientific and experimental methods, the work remained strangely afar from the concerns of practical life. In the first decades the psychological laboratory work seemed to remain a most impractical research of scholarly theorists. Nobody gave any attention to the fact that the material which those scholars analyzed and investigated, namely the human feeling and will, memory and attention, perception and judgment, sensation and emotion, were the material from which our daily life with all its human interests is built up. You as engineers can hardly imagine physicists

* An address delivered at the mid-winter convention of the Illuminating Engineering Society, New York, February 10, 11, 1916.

closeted in their laboratories with their knowledge of steam power and electrodynamics and nobody asking whether that new insight might not be made useful for toiling mankind. But this was exactly the psychological situation up to the threshold of the twentieth century. In every schoolroom and every courtroom, in every hospital and in every industrial plant the human factor and the mental energies were the most important parts of the whole interplay; and yet neither the teacher nor the lawyer, neither the physician nor the manager showed any interest in the new psychological discoveries.

The educational work awoke first. The teachers recognized the crying need to have a fuller grasp of the pupils' memory, attention, intellect and will. The medical men, too, for a long while looked with indifference at psychological progress. To-day the new tendencies can be felt in every corner of the field. Psychotherapy became influential, neurology was intertwined with physiological psychology and to-day the physician who diagnoses mental abnormities and diseases can no longer afford to ignore the subtle experimental methods for tracing the disturbances of character and temperament, of intelligence and of the mind's elementary functions.

It is only natural that the lawyers should have followed more slowly. The methods of law must be conservative. Yet the observations of the psychologist became so impressive that even the jurist had to listen. All the questions of evidence have appeared in a new light since the psychology of testimony became a favorite topic of the applied psychologist and the motives of crime and the effects of punishment were at last seen in their psychological setting. The latest comers were the men of practical affairs. Everywhere, and surely nowhere more than in this country, the leaders of commerce and transportation and industry showed a wonderful eagerness to consult the physical and chemical and mechanical engineer, but even ten years ago they would have hardly listened to the strange message that they might also learn from the psychological engineer. But when finally the new hour struck the advance toward psychology in the economic field was perhaps quicker than in any other. To-day the whole country resounds with the call for the psychologist in the business world. Every week sees new organizations for industrial

or commercial psychology. The employers call psychological experts into their factories and mills and the employees join psychological courses. It began with an outer problem of the business world, the question of the effective advertisement. The advertising industry involves billions, and everything depends upon the right effect on the attention, memory, suggestibility and desire of the customer. Only the psychologist specializes in the study of these mental functions, and as soon as he began to experiment on the means of propaganda and display, the contact between the new science and business was established. But a larger problem quickly pushed itself into the foreground. Through two well known movements, that toward vocational guidance for boys and girls when they leave school, and that toward scientific management in the factories, the interest of the community became focused on the need of selecting men and women for work with reference to their individual fitness and that means first of all with reference to their mental traits. Experimental tests were worked out to determine quickly the individual differences of the minds and to correlate them to the particular needs of an individual position. The aim was to recognize the special type of attention or quickness of reaction or acuity of observation or span of memory or habit of learning or exactitude of impulse and so on before the man was appointed as motorman or as locomotive engineer or as typesetter or as electrician. It is probable that the experimental study of individual fitness will remain the central problem of industrial psychology. At present surely we stand only at the foot of the ladder. But there remain plenty of other too much neglected questions which the psychologist must answer when they arise in the workshops, mills and factories. How is the technique to be learned? Above all, how is the technique to be adjusted to the general dispositions of the mind? The organization of motor impulses, the rhythm, the uniformity and monotony of work, the fatigue, the acquisition of habits in work, the influence of stimuli—everything suggests exactly the kind of analysis which only the psychological laboratory can furnish.

In the midst of this new group of inquiries the engineer must raise the question how light affects the industrial output. As yet we know far too little how the working man profits

from changes in the illumination where he is working. Some of the scientific management engineers have secured marked improvements in certain mills by altering the position of the lights or the station of the worker with reference to the window, the intensity of the light or its diffusion. Yet all this has been attained by mere trying. We still lack any exact investigations. In the Harvard Psychological Laboratory we have approached the field with regard to different color effects and different intensities of light. One of my young assistants, Mr. Pressy, has been engaged for a long while in measuring the psychological effects of red, green, yellow, blue, and white light, all of equal intensity. The subject remains for five minutes entirely under the influence of one color and then goes through tests by which his rapidity of tapping movements, his exactitude of pressure movement, his memory, his power of discrimination and other functions of import for technical life are measured. The results show marked individual differences. We find subjects with pronounced intolerance for a particular color, for instance one whose mental processes take 20 per cent. more time under the influence of red or another whose memory work shows an unusual improvement under green light. But practically of more importance are the constant differences indicated by the averages from many subjects. The tapping activity shows the most uniform rate with green, is decidedly quicker with red and slower with blue. Arithmetical work is strongly improved by red, in a less marked way by an increase of brightness. A characteristic result of his investigations, which is not yet closed, is the independence of such objective results from the subjective feelings. The colored lights which are felt as pleasant produce by no means more favorable conditions for working efficiency than those which are felt as unpleasant. The industrial world will have to give much keener attention to the conditions of light in the producing plants and will have to consult the psychologist at every step.

But the illuminating engineers who inquire about the relation of psychology and light think less of the light needed for the manufacturing of technical products than of the light which their particular product, the lamp, is shedding. Of course, they did not wait for the psychologist to ask whether an illumination

is agreeable or not, whether the lighted room is fit for readers or needleworkers, whether the lamps on the street are bright enough to protect against accidents. But whether such questions were answered by common sense or by reference to some textbooks, in any case such queries about the visual impression reached only the periphery of the psychological problem. They dealt essentially with the psycho-physiological functions of the eye and had hardly any bearing on the higher mental processes. Even when the contact with the laboratory was secured the interest seemed confined to acuity of vision and to physiological states of the retina like the visual adaptation, contrast effects, and so on. This was natural from the standpoint of the illuminating engineer who begins, of course, with a purely physical measurement of the light intensity and to whom the impressions of the persons with whom he experiments offer only a kind of subjective supplement to the objective photometry. We have even heard the voices of opponents who warn the engineers against the introduction of such unreliable and fluctuating elements as mental measurements of illuminations instead of leaving everything to the strictly physical standardization. The experimental psychologist of to-day cannot take such a warning seriously. He knows that all illumination is made for mental consumption. The physical standards alone are right when the current is to give heat, but when it is to give light not for photographing but for illuminating purposes the human mind alone can furnish the standard. But the psychologist must add at once that the mind is not really consulted as long as only the acuity of vision and the light sensations as such are examined. He must rather emphasize, and all modern psychological knowledge backs his demand, that every illumination problem ought to be grasped in its whole psychological setting. Nothing reaches our eye which does not touch our whole personality. The visual impression is the starting point for a whole hierarchy of mental reactions. Every practical situation in which we use light demands more from us than mere awareness of the visual stimulus. Each time our perceptions and apperceptions, our feeling and our attention, our imagination and our will are involved. This is indeed the fundamental suggestion of the psychologist: Approach every one of your problems with due regard to the whole complex setting of the mind.

The visual impression itself must always be regarded as a mere fraction of the effects which you secure. But secondly, remove these mental inquiries from mere haphazard judgments by a systematic turning to the laboratory experiment. The engineer knows well from his physical work that experimenting never means to reproduce the practical situation in the dimensions of reality. A little model on the laboratory table can furnish all the needed knowledge. It is not different with the mental operations. The psychological experiment too does not depend upon its being carried out under the actual practical conditions. Any artificial laboratory setting in which as in a miniature model the mental processes enter into play may be of service. Only under such simplified conditions can we vary the setting from test to test and study the resulting changes in the mental reactions.

Let me give you an illustration. Two years ago when the National Electric Light Association asked for my advice with reference to the street lighting problem, I at once wrote in my reply: "The mere possibility of visual discrimination does not ensure comfort and still less safety on the street. The most essential point is to have an illumination by which the attention is kept vivid and all the mental functions active. Fair chances to see are of small use if the pedestrian or the driver come into a benumbed state in which his attention is dulled and in which his reactions are slow. Offhand and without having carried on any experiments whatever I should be inclined to say that a uniform illumination would be unfavorable for the attention. Our attention is naturally fluctuating and will best be kept awake if the illumination produces an alternation between tension and relaxation. This demands that there be darker regions between the lighted fields." Now a psychologist ought never to say anything "offhand and without having carried on experiments." I was, therefore, very glad when my assistant, Dr. Burtt, was invited to participate in those interesting experiments which were carried on here in New York in the summer of 1914 by the Joint Street Lighting Committee. We agreed that experiments on quickness of reaction time, both simple reactions and complex choice reactions, ought to be made on the streets under different systems of illumination. A second set of experiments referred directly to the power of attention. The subject had to disentangle several

geometrical figures out of a complex group of forms. And finally a test of motor co-ordination was arranged. The mechanical devices for all three tests were so constructed that the response of the individual was independent from the darkness or lightness of the spot at which they were carried on. The reaction was made to various sound stimuli and the forms to be analyzed were seen in a box with constant illumination. The results were objectively measured in hundredths of a second. The tests of motor co-ordination were registered by the signal magnet on the kymograph. The three tests were made on men who had walked through streets of either uniform or non-uniform illumination. All three tests together allowed a fair decision concerning a man's individual freshness and mental alertness under the two systems of light. You may have glanced over Dr. Burtt's report, and you may have seen how the results of his experiments, filling the fair evenings of six summer weeks, confirmed my expectations in full detail. His tables show that for instance the auditory choice reaction is, under the non-uniform illumination, in every case shorter and on the average 17 per cent. shorter than under uniform lighting. The attention as indicated by the test with form analysis is under non-uniform illumination superior in twenty-six out of thirty-one series. Even the motor co-ordination was in 77 per cent. of the series better developed under non-uniform lighting. But Dr. Burtt's report to the committee did not contain the second part of his investigation, which best illustrates my point. After completing these experiments on the street, he repeated the experiments throughout the last year under the artificial conditions of the Harvard Psychological Laboratory. There we equipped a black room with apparatus which allowed us to imitate the essential states of mind and at the same time to settle those questions which remained doubtful in the actual street tests. In practical life we cannot resolve the complex situation into its elements. In the psychological laboratory we can aim toward such a goal. Dr. Burtt asked himself, for instance, whether the superiority of the attention in streets with non-uniform light depended upon the fact that the pedestrian himself was alternatingly in light and in dark regions or whether it resulted from the outlook into a street in which light and dark strips succeeded one another. Again he had to meet the objec-

tion that non-uniform light on the streets produced better results in the tests because the man who passes a dark region voluntarily forces his attention to a higher pitch in order to discriminate the obstacles or irregularities on the surface. But the chief problem remained the difference between the two lighting systems. In the interest of the first problem our laboratory subjects, who are always post-graduate university students, reacted on sounds, analyzed complex figures and so on, while the light slowly grew dimmer and brighter alternatingly in the rhythm in which a man would pass from light to shadow in walking through a street with non-uniform illumination. To reproduce the second factor, the lights and shadows on the surface of the street, the illumination of the room was kept constant, but patterns of lights and shadows moved over the wall. In both groups of experiments the intensities, the pace of transition and the amount of the differences were kept quite similar to the street conditions. The results for all the laboratory experiments together substantiate the outcome of the street tests. The non-uniform light is more favorable for every type of tested mental activity. Auditory reaction time is superior under such lighting in 80 per cent. of the series, visual reaction time is quicker in 65 per cent. The comparison between the effects of the moving strips of shadow and the rhythmical increase and decrease of light shows that much depends upon the speed. The score of attention is high when the shadows move in a cycle of 85 seconds, but low when they move as quickly as 25 seconds, while the alternation of strong and weak light in the rhythm of 25 seconds produces a decided heightening of the mental powers. I cannot enter into details here. I still want to mention only that Dr. Burtt's experiments made it clear that a voluntary re-enforcement of attention in the darker regions is not responsible for the superior achievement. For our purpose not the results are important but the method. If our laboratory tests can analyze the real elements which enter into the situation, it must be more advantageous to study the question under the pure conditions of the psychological workshop where every factor can be standardized and varied at will than on the street where the manifold conditions confuse the issues. As soon as the principles are recognized,

it is not difficult to take account of all those disturbing elements by which the street differs from the quietude of the workroom.

But light not only serves for illuminating the surroundings. It may work directly on the eye as a signal. The whole railroad service depends upon this function. Again I may illustrate the help which experimental psychology can offer by pointing to a yet unpublished investigation in the Harvard Psychological Laboratory. Mr. Fry, connected with the Pennsylvania Railroad, spent the last year in our laboratory engaged in testing the different mental influences of railroad light signals on the mind of the engineer in the locomotive. We had secured material from all important railways of the country. Their confidential reports made it evident that among the cases of accidents traced to signal failures 85 per cent. were caused by misinterpretations and only 15 per cent. were due to the signal itself not working properly. This misinterpretation is a psychological process, which we had to study under all possible conditions. The levers of the locomotive were replaced by similar levers in a dark cabinet, each connected with electric markers which made it possible to read the time between the flashing up of the signal and the reactions of the hands in fractions of a second. We had our semaphores, we had our white and green and yellow and red lights in different positions and in different combinations. Long series of signals could follow one another as they would appear to an engineer during a long night trip. You may say that the complexity of the actual situation on the road is much greater and the demands upon the mind therefore much subtler than in a protected laboratory room. There are rains and fogs; but we were able to imitate their mental effects. Large smoked glass plates at different distances from the light gave us all that dimming which the fogs of various intensities could produce and we could study which signals suffered most from them. We tested the important improvements which have been proposed, the beams of light and so on. Above all, we studied again not simply the isolated light function but the whole mental reaction of the man with all his shades of memory and attention and training and fatigue.

The time alloted to me does not allow my entering into other illustrations, but there is no field of illumination work which has not its psychological aspect, and is not accessible to the methods

of psychological experiment. The interior illumination with its problems of direct and indirect light is an especially fertile region for psychological study. How was it possible to introduce for indirect illumination in the home those lamps which are not translucent and create a big black disk in the midst of the lighted ceiling? They are disappearing to-day, but they would never have made their debut if the warning of the psychologist had been heeded. And with great scepticism he hears certain inside illumination praised because there are no shadows. He knows how much shadows help toward an easy grasp and an inner organization of the surroundings and through them to the comfort of the mind. And before I close, let me mention at least that world which the honored hero of this your meeting, Edison, has opened to us, the world of the film. We have been led from triumph to triumph there by the kinematoscopic technician. But only in most recent days has it been recognized how large must be the mental factor in the success of the moving pictures and how much of it is open to psychological experiment. We know now from such mental laboratory studies that some of the physical problems of producing the light for the screen were incorrectly put. The longest possible exposure of the picture, the shortest pause between two succeeding pictures is not the most favorable condition for the strongest effect, although this appeared to the physicist a matter of course. Your physical instruments are wonderfully complex. But if it comes to a test the mind of man proves to be the still more complex instrument, after all. You have no longer any right to settle the psychological parts of your problem by common sense only. The bridge from the physical to the psychological laboratory is now firmly built, and whenever you cross it you will find a ready welcome in the camp of the hopeful psychologists.

LIGHT—A DOMINANT FORCE IN LIFE PROCESSES.*

BY F. PARK LEWIS.

Synopsis: The effects of visible light and radiations at each end of the spectrum upon the living organisms and tissues is given in this address. The curative powers of radiant energy is briefly dealt with. The photographing of objects through opaque screens placed between the sensatized plate and the source of invisible radiation is used as illustrative of the effects of radiation below the visible spectrum. The author further describes the effect of light on plant life and concludes the address by pointing out that the activities of the universe are dependent upon the manifestations of force through the ether—radiant energy being one form of this phenomena.

In the little town of Perrysburg, situated some 40 miles from Buffalo and 14 miles back in the hills from Lake Erie, is being enacted what to the uninitiated would seem to be a modern miracle Indeed. I am not sure at all, that, even to those who are most profoundly learned in the character of the activities involved, the miraculous manifestations would not seem to be over emphasized.

Upon an elevation 1,500 or 1,600 ft. above sea level a group of spacious buildings have been erected. Most of these are surrounded by glass enclosed verandas—the tops and sides of which are wholly open except in time of storm. Lying on beds in these different pavillions, with their naked bodies exposed to the air and sunshine, are victims, many of them children, of active tubercular disease; some involving the bones, some the joints, some the intestines, some the skin, many of them have been the subjects of repeated surgical operations which have been without benefit. They are put in the cold open air, unclothed, except for a loin cloth, while the sun is allowed to pour its beneficent rays onto, into and through them; not all at once,—we have been so sheltered from nature's active forces that we cannot endure the powerful effects which are excited, and the cellular activities when they are suddenly aroused produce violent reactions. There-

* An address delivered at the mid-winter convention of the Illuminating Engineering Society, New York, February 10, 11, 1916.

fore, the first exposure to the rays of the sun is of a part of the body only. A portion of one foot is left exposed for a period of five minutes; the rest of the body being carefully covered. The next day the sun is allowed to shine on both feet for a little longer time, the day following one of the ankles is included, and the next day the other, and so by degrees the whole body with the exception of the head, is exposed for the entire day to these life giving rays. As the sunshine pours down upon the skin a rich coat of tan is developed, and to the degree that the pigment reaction is obtained the normal functions are restored, the fistulous ulcers are healed, the diseased joints are made well again, and the children as naked and as brown almost as Hottentots, may be seen in the winter with snow shoes on their otherwise bare feet, drawing one another on their sleighs and shouting and playing with a joyous abandon that they probably have never before known in the cramped lives of their close built city homes. This is the Heliotherapy of Rollier and is a demonstration of the profound effects of ether vibrations over physiological functions.

While in all probability the full potentialities of the curative power of radiant energy is only beginning to be realized, it has always been known that sunshine is essential to health. This is a matter of such common knowledge that the Italians have expressed it in a proverb in which they say that "All diseases come in the dark and are cured in the sun." How true this may be only further research will determine.

But our experience already acquired with other forms of radiant energy such as the ultra-violet light, the X-ray, the invisible infra-red rays, and radium have already demonstrated that those of us who have to deal with light are concerning ourselves with one of the great elemental forces, and it can be considered only in relation to life itself. It will not be necessary, before this audience, to refer to the effect of light on the living organisms as demonstrated by many experiments of recent years. You are as familiar as I with the word of Jaques Loeb, Mast and others on the remarkable phenomena known as heliotropism.

We know that many living forms respond to the stimulus of light and will gather together in the illuminated part of the aquarium, avoiding that part which has been darkened, that they are

oriented by light, some moving toward it, others from it. It is this effect that controls the growth of spirals, that draws the moth to the lamp flame, the caterpillar to the tree top and the animalcule to the surface of the sea.

Many exact observations have also been made of the effect of different wave lengths on growing plants and animals, but we will not take time to recall observations that are so easily accessible. This young twentieth century has, however, swept us away from some old moorings that we had deemed fixed beyond the possibility of change. We have been obliged to restate fundamental principles involving the nature of the universe and upon these may be rebuilded our conception of life itself.

The observations of the French physicist, LeBon, on the effects produced by the invisible rays of the spectrum and the conclusions to which they give warrant have not been so widely considered and their relevancy will permit perhaps a moment's reference to them.

It has been well known, of course, since our own Professor Langley gave us the bolometer, that when sunlight is filtered through a prism the visible portion constituting our spectrum is exceedingly small as compared with the many octaves below the red of which the human eye is not conscious. But we have not realized to what extent these invisible vibrations eminated from all objects. As was startingly disclosed by the vibrations which Roentgen discovered, opacity and transparency are relative terms merely. There are no tangible bodies which are absolutely solid, none which are inpenetrable to some of the forces of nature.

Equally unexpected are the properties of that invisible radiance which LeBon has paradoxically called "Black Light," a knowledge of the mysteries of which is measured only by the limitations of our own senses. The facts are no doubt well known to you. Certain substances, especially the phosphorescent sulphides, after having been exposed for a short time to the sun become exceedingly sensitive to light. They respond with a degree of sensitiveness to the rays of the spectrum almost equal to that of the photographic plate. The sulphide of zinc, which gives green phosphorescence, is especially responsive to the rays from the green far down into the infra-red.

It is owing to this fact that the transparency of otherwise opaque objects has been shown. Objects having been exposed to the sunlight for many months emit an invisible phosphorescence, the rays of which respond to laws governing visible light, being capable of refraction, polarization, and actinism in its effect on photographic plates. It has the same spectrum as light but is wholly invisible to the human eye.

By means of these unseen radiations may be demonstrated the phenomenon of seeing in the dark.

A statuette, covered with copal varnish, in which sulphide of calcium has been dissolved, is exposed for a few seconds to the light of the sun. It is then left for several days until it has become dark and has ceased to show any visible luminosity. It is then taken into a totally dark photographic cellar and placed before a camera which has been previously focussed. An exposure is made for a number of days and a photograph is produced as clear as that obtained by daylight and as distinctly showing the shadows. It is shown, too, that by changing its position these shadows can be altered just as would be done by visible light.

In further demonstrating the presence and effect of the invisible light rays of a phosphorescent body a statuette similarly covered is allowed to become entirely dark. A candle flame, the infra-red spectrum of which is much greater than that of daylight, is entirely enclosed in a black cardboard box excluding every ray of visible light. Both are placed upon a table in a darkened room. Through the enveloping materials surrounding the light and through the darkness of the chamber the invisible vibrations from the lamp unite with the equally invisible rays coming from the statuette and we are conscious of a self-luminous figure, standing out from the blackness by which it is surrounded.

Among the most surprising manifestations of this invisible light in darkness is the quality which it possesses of photographing images through opaque bodies.

A plate of mica, which has been made opaque by Japan varnish, is put in front of a focussing tube in a camera. The object to be reproduced has previously been focussed and the plate placed in front of the diaphragm. A screen of sulphide of zinc is then illuminated by daylight and placed in the dark slide of the camera

as if it were a photographic plate. It is then exposed in the ordinary way for a period of time varying with the light.

The frame is then closed and the plate is taken into an absolutely dark room from which all light, especially the red, has been excluded. If it is then opened the phosphorescent image will be seen on the plate. It can be preserved by placing it on the surface of the gelato-bromide plate for a few minutes and then treated in the ordinary manner.

Down to the absolute zero of temperature all bodies incessantly radiate waves of light, invisible to us except when reinforced by daylight, but probably perceptible to nocturnal animals and birds. It is quite likely that the tapetum, which makes a cat's eye shine in the dark, has a phosphorescent quality enabling it to see the invisible rays that all objects emit. Especially is this true of the warm bodies of the higher animals which we fail to see in the dark only because our eyes are not sensible to these long wave radiations.

The curious fact has been brought out that black paper, which entirely shuts out the light rays, is perfectly transparent to the invisible infra-red radiations.

A green house may be made absolutely dark with black paper, but still much the larger part of the light passes through as the visible rays which have been excluded constitute so small a portion of the spectrum. The invisible rays which are transmitted through the black paper manifest all the phenomena of visible light although the surroundings to the ordinary eye are in absolute blackness.

The effect on plant life is peculiar. It seems to stimulate an activity which is quickly spent. Seeds germinate more quickly but the plants die soon. Plants grown in the daylight and then exposed to the long wave invisible radiations behave differently. Some do not flower, some wither, some grow more rapidly, some are unchanged, some, as tomatoes, become absolutely white.

These qualities of radiant energy are mentioned not for the purpose of emphasizing the singularity of the phenomena which are produced, but that we may more clearly grasp the thought that it is one manifestation of the force that holds together the elements of the universe.

The atom is no more in the eyes of science the ultimate division of matter. The atom has become in itself a universe. Professor Rakestraw in speaking of it says: "The mass of an electron is only one-twelve-hundredth of that of a hydrogen atom which has hitherto been considered the smallest particle with which we have dealt."

Although the electric charge, which exists upon an electron, seems exceedingly small, it is so large compared to the size of the electron that if two electrons were placed one centimeter apart in a vacuum they would repel each other with a force a trillion, trillion times greater than the attraction of gravity. Indeed the force which we are considering is so great that if we regard the electric current to be gas, it exerts a pressure thousands of times greater than the atmosphere.

If, as Sir Oliver Lodge asserts, the ether is undifferentiated, is stationary, is susceptible to strain but not to motion, that it is the receptacle of potential not of locomotive kinetic energy, then matter as such is not a mode of motion in it. It is simply a vortex stress. When matter seems to move it must mean simply a transference of energy, and as forces pass from place to place, holding together certain forms and shapes, that which must occur must be the replacement of one group of vortices by another until their final dissipation occurs. And if the ether is universal and inelastic, as it must be if it is indivisable, then there can be no dissipation of force. All of the stresses in this ether which may occur, whether they be in the form of radiant energy, which is probably another name for electric energy, stored up in the chlorophyl of the plant or in the structural cell of a human brain, of magnetic influences, or of chemical affinities, are eternal and indestructible, and extend continuously from the beginning to the end of time.

When we endeavor to realize the infinite minuteness of an atom, with electrons shooting through it with the rapidity of light, the human mind stops,—unable to follow it.

If, says Rakestraw, "We imagine the earth reduced to the size of an electron,—the total visible universe, with its millions of stars, would approximate the size of a human blood corpuscle. The revolutions of the planets about the sun would reduce to the

same order as those of the electrons within the atom. Their frequency of vibration would produce a visible spectrum as do the electrons. The distance between stars would correspond to that between molecules of air. In fact we would have almost a perfect microcosm."

But when this is contrasted with the stars in infinitudes of space, stars which have lost their brightness while still their light continues to shine, so remote are they from us, it must be that in these repetitions we find that continuity which holds the universe together.

Be that as it may, we cannot approach these great questions heedlessly. If we go as far as science will take us we must believe that the ether is an undifferentiated and an indivisible substance filling all space, that the atom is a vortex formed in the ether, and that the ion is still another vortex within the atom itself, but the space within the atom through which the activities of the electron are manifested must be filled with ether, and the electric charge which the ion bears is simply like galvanism and light,—a stress in the ether. If the atom, the ion, and the electron are simply manifestations of force in the indivisible, and, therefore, inpenetrable, and, therefore, solid ether, there can be no concrete motile matter, and that which appears to be a change of position in space is a change of energies, so that with every motion a new stress occurs in a new part of the ether, and it is this change of stress, resulting in a constant change of activities, carried on with the rapidity of the action of light that constitutes, not that form of motion, but that form of energy, which we know as matter.

So we must come back to the conclusion that all of the activities in the universe are dependent upon the manifestation of force through the ether, and that all structure, animate and inanimate, is held together by inter-acting forces, of which the ether constitutes the web and the woof.

So let those of us who are dealing with light and electricity realize that we are directing the essential forces of all nature and life, and let us take the shoes from off our feet for the ground upon which we are treading is holy ground.

THE ARCHITECT AND ILLUMINATION.*

BY CHARLES ROLLINSON LAMB

I make no pretence of being an illuminating engineer, but I speak to you from the viewpoint of the architect on matters pertaining to illumination.

Many of you can carry your minds back to the Expositions which preceded the Hudson-Fulton celebration and in so doing note the gradual development of various methods of lighting and the tremendous change in the field of illuminating engineering. Some of you have undoubtedly attended the exposition at San Francisco, which has just closed. I shall not have to recall to you all the changes in lighting represented at this exposition as compared with those which preceded it.

A new profession has been evolved which is called illuminating engineering, so that I find in my own time, supplementing my profession, this new profession which must assume a very large responsibility because the problem is for you, and not for us who construct the building, to let what we do be seen of men. There are so many different methods of attacking the problem of properly lighting any building and so many ways in which the illuminating engineer can co-operate with the architect, that I ask you to give this question your most serious consideration whenever you are called into consultation with the architect.

I hope that no important building will hereafter be constructed without some competent illuminating engineer being called into consultation before the plans are completed and not after the building is erected. The proper emphasis placed by good lighting upon the architectural construction of the building is never secured when there is a lack of co-operation between the architect and the illuminating engineer. The illumination of large spaces has great possibilities when the architect and the lighting engineer work in co-operation, but to my mind successful lighting can never be obtained when consideration of the lighting problems is postponed until after the building has been constructed.

* An address given at the mid-winter convention of the Illuminating Engineering Society, New York, February 10, 11, 1916.

That some architects are unwilling or fail to consult with the illuminating engineer is true, but I think that most of the best architects are realizing that a consultation with the members of this profession is essential. The architect has always been willing to allow others to suggest the necessary heating apparatus, ventilating schemes, etc., but it is only very recently that architects have realized the tremendous potentialities of illumination—the power the illuminating engineer has to emphasize the dignity of all architecture. The problem of determining the proper lighting of a building at night must be solved by the illuminating engineer; you see I am placing that part of the responsibilities on your shoulders, where I really believe it belongs.

Yours is a great profession and the possibilities of the future are as yet unrevealed as to what can be done with the lighting power that God has given us. The future is a bright one in every sense of the word. Many systems have been tried, the indirect lighting has proved successful as has also the use of hidden lamps, and I understand that very satisfactory results have been obtained in recess lighting, with lamps concealed behind windows, arches and other openings. However, to my mind all these still lack individuality and the great charm of color.

There are three factors that form the triangle that makes the unity of this art possible; one is the responsibility of the city to its citizens to illuminate properly the streets and parks and all the properties controlled by the city; the responsibility to not only furnish light but sufficient light to make the street safe and to illuminate the public buildings adequately. The second side of the triangle is that which applies to the individuals who construct large buildings, working in conformity with the lighting regulation of the city. The third side of the triangle is your responsibility; to see that all this is well done; and that task, of course, I leave to you.

TRANSACTIONS

OF THE

Illuminating Engineering Society

NO. 6, 1916

PART II

Miscellaneous Notes

New Sustaining Members.

The following four companies were elected sustaining members of the Society at a meeting of the Council Executive Committee held July 18, 1916:

CUMBERLAND COUNTY POWER & LIGHT Co.
453 Congress St., Portland, Me.

FULTON LIGHT, HEAT & POWER CO.
103 Oneida St., Fulton, N. Y.

CENTRAL HUDSON GAS & ELECTRIC CO.
129 Broadway, Newburgh, N. Y.

HYGRADE LAMP CO.
Salem, Mass.

New Members.

The following three applicants were elected members of the Society at a meeting of the Council Executive Committee held July 18, 1916:

HODGSON, CHARLES I.
Chief Inspector of Lighting, Commercial Dept., Brooklyn Union Gas Co., 176 Remsen St., Brooklyn, N. Y.

KARRER, ENOCH
Assistant in Physical Research, United Gas Improvement Co., 3101 Passyunk Ave., Philadelphia, Pa.

KORTHAUS, EMIL
Assistant Manager, Commercial Dept., Brooklyn Union Gas Co., 176 Remsen St., Brooklyn, N. Y.

New Associate Members.

The following five applicants were elected associate members at a Council Executive Committee meeting held July 18, 1916:

BRADEN, MORRIS G.
Salesman, Ivanhoe-Regent Works of General Electric Co., 219 McKnight Bldg., Minneapolis, Minn.

CRAWFORD, R. D.
Electrician, B. F. Goodrich Co., Akron, Ohio.

JONES, R. C.
Secretary and Treasurer, San Antonio Gas & Electric Co., 305 East Houston St., San Antonio, Tex.

PHILLIPS, CHARLES TRAVERS
Consulting Engineer, Pacific Bldg., San Francisco, Cal.

VALES, ALVARO ROSADO
Experimental work in Mexico, 1457 Broadway, New York, N. Y.

Transfers to Grade of Member.

The following four associate members were transferred to the grade of member at a Council Executive Committee meeting held July 18, 1916:

ASHLEY, EDWARD E., JR.
Mechanical and Electrical Engineer, Starrett & Van Vleck, 8 West 40th St., New York, N. Y.

CURTIS, AUGUSTUS DARWIN
President, National X-Ray Reflector Co., 235 West Jackson Blvd., Chicago, Ill.

GILLINDER, EDWIN B.
Glass Manufacturer, Port Jervis, N. Y.

LIVINGSTON, HERMAN
Hydrocarbon Engineer, Aetna Explosives Co., 120 Broadway, New York, N. Y.

Tenth Annual Convention—1916.

The tenth annual convention of the Illuminating Engineering Society will be held at the Bellevue-Stratford Hotel, Philadelphia, Pa., Sept. 18-20, 1916. The arrangements for the business and technical sessions and for the entertainment features are now nearing completion.

The convention will open on Monday ıorning, Sept. 18th, with the President's ldress of welcome following which ill be given the reports of the Comittee on Nomenclature and Standards, nd the Committee on Progress. Beinning Monday afternoon and continng on Tuesday and Wednesday the ollowing tentative program of papers ill be presented:

Colored Glasses for Illuminating Engineering," by Mr. H. P. Gage.

Lighting of Cleveland Museum of Art," by Dr. E. P. Hyde.

Illuminating Engineering Photographs," by B. E. Norris.

The Effects of Brightness and Contrast of Vision," by Dr. P. G. Nutting.

Apparent Brightness and Its Properties," by Dr. L. T. Troland.

Integrating Spheres," by F. A. Benford.

Street Lighting," by Ward Harrison.

Gas and Electric Lighting in the Home," by C. H. French and J. C. Van Gieson.

Optic Projection as a Problem in Illumination," by J. A. Orange.

Forced Life Testing of Incandescent Lamps," by L. J. Lewinson.

Industrial Lighting by Gas," by J. D. Lee.

'Gas Illumination of the Philadelphia Civic Exposition," by C. S. Snyder and F. H. Gilpin.

'Experiments on the Eye with Pendent Reflectors of Different Densities," by Drs. C. E. Ferree and G. Rand.

'Studies of Economics in Office Building Lighting," by S. G. Hibben.

'Recent Developments in Prismatic Glassware," by C. W. Roosa and H. L. Jenkins.

'Probability Curves as Applied to Photometric Measurements," by W. G. Housekeeper.

Special features of the entertainment program are as follows:

Sept. 18th, Monday—Automobile trip for visiting ladies to a suburban country club, where luncheon will be served.

Monday Evening—Reception to President Steinmetz, Bellevue-Stratford Rose Garden, followed by piano recital and dance.

Sept. 19th, Tuesday—Automobile trip through beautiful suburban Philadelphia to Valley Forge National Park. Dinner will be served the visiting ladies at Washington Inn.

Tuesday Evening—Tenth annual banquet at the Bellevue-Stratford Rose Garden.

Illuminating Engineering Lecture Course.

A lecture course consisting of a comprehensive selection of addresses by the leading scientists and engineers in the field of illumination and allied sciences will be given at the University of Pennsylvania, Philadelphia, Pa., Sept. 21-28, 1916. This series of lectures will be given jointly under the auspices of the Illuminating Engineering Society and the University of Pennsylvania.

This course is designed to reach those engineers, university and college instructors, central station representatives, architects, and students who are directly interested in adequate, pleasing and harmonious illumination. The course includes the regular lectures, visits to manufacturing and lighting companies, illumination laboratories, studies of notable installations and an exhibit of the latest devices and sample installations in the field of lighting. The price of tickets for the lecture course has been fixed at $25.00 and includes admission to all lectures and functions con-

nected therewith. Tickets and further information concerning the course may be obtained by communicating with Clarence L. Law, Irving Place and 15th St., New York, N. Y. The preliminary list of lecture subjects is as follows:

(A) General.

"Illumination Units and Calculations," by A. S. McAllister.

"Modern Photometry," by Clayton H. Sharp.

"The Principles of Interior Illumination" (two lectures). Committee: J. R. Cravath, Chairman; Ward Harrison, Robert ff. Pierce.

"The Principles of Exterior Illumination," by Louis Bell.

"Color in Lighting," by M. Luckiesh.

"Architectural and Decorative Aspects of Lighting," by Guy Lowell.

"Recent Developments in Electric Lighting Appliances," by G. H. Stickney.

"Recent Developments in Gas Lighting Appliances," by Robert ff. Pierce.

"Modern Lighting Accessories," by W. F. Little.

(B) Special Lectures on Interior Illumination.

"The Lighting of Factories, Mills and Workshops," by C. E. Clewell.

"The Lighting of Offices, Stores and Shop Windows," by Norman Macbeth.

"The Lighting of Schools, Auditoriums and Libraries," by F. A. Vaughn.

"The Lighting of Churches," by E. G. Perrot.

"The Lighting of the Home," by W. H. Jordan.

"Railway Car Lighting," by C. E. Hulse.

(C) Special Lectures on Exterior Illumination.

"Street Lighting" (two lectures), by P. S. Millar and C. F. Lacombe.

"The Lighting of Yards, Docks and Other Outside Works," by J. L. Minick.

"Headlights, Searchlights and Projectors," by E. J. Edwards.

"Sign Lighting," by L. G. Shepard.

"Building Exterior, Exposition and Pageant Lighting," by W. D'A. Ryan.

WILLIAM J. SERRILL,

President of the Illuminating Engineering Society,

1916 - 1917.

TRANSACTIONS
OF THE
Illuminating Engineering Society

VOL. XI — OCTOBER 10, 1916 — NO. 7

LIGHTING IN THE ARMY.*

BY CAPT. EDWARD D. ARDERY, U. S. A.

Synopsis: This paper deals with the applications of various illuminants to the unusual demands of the army. The factors which govern the selection of the candle, gasoline torch, gas and electric lamp for the specific need of camp life or battle manœuvres are outlined. Special significance is given to the necessary lighting of certain parts of artillery and coast defense guns together with auxiliary range-finding instruments, etc. The paper concludes with a review of the functions of the search-light as used in the army.

In the army our use of illuminants causes us to have recourse, for one purpose or another, to bonfires, fireworks, candles, kerosene, gasoline, gas, acetylene, and electricity. Besides these, moonlight enables us to prosecute or to detect night operations of troops in the field; while the sun affords a means of signalling with heliographs. The latter two, however, are hardly pertinent to the present discussion. The same may be said of bonfires, but, nevertheless, I shall indicate how they serve a purpose.

In the absence of something better, the camp fire affords a means—not recommended by sincere eye specialists—for the soldier to read or write while in the field. Bonfires may be placed on the banks of a stream to indicate safe points for crossing. To mark the area within which it is safe for aircraft to make a landing is a not infrequent use to which fires are put.

When some other suitable means are not at hand, candles are issued to the troops for use in their tents, although serving as a hazard to shelters and equipment. Some stable lanterns and

* An address delivered before the New York Section of the Illuminating Engineering Society, October 14, 1916.

This address is closely related to the paper on "Illumination in the Navy," by C. S. McDowell, which appeared in vol. XI, No. 5, p. 573, of the TRANSACTIONS, July 20, 1916.

photographic darkroom lanterns depend on candles for their source of illumination.

Kerosene is provided for lanterns used after dark in making roll calls and during inspection of tents or quarters. On night marches lanterns are sometimes used to lead the way. Lanterns for laying out defensive works and trenches are so constructed as to throw the light rays downward to guard against being seen by the enemy. Gasoline torches are sometimes used as in commercial practice.

Electricity, gas, and sometimes kerosene are found as illuminants in the barracks and officers' quarters at the various army posts. On account of the open flame and the danger from explosive mixtures of gases, gas and acetylene are not considered suitable for use in magazines at our seacoast forts. The abnormal air pressures set up as a result of the firing of large guns would also often extinguish gas lights and kerosene lanterns. On some army posts, where electric power is not available, exterior lighting is done by gas or kerosene. Acetylene is well adapted for illuminating tents in which reading or clerical work is to be done, for in this case it is advisable to use a type of lamp that has the flame inside a chimney; otherwise the flickering caused by air currents is more or less disagreeable and trying to the eyes.

For outdoor work the regular torchlike flame with or without a reflector is satisfactory. In making or breaking camp at night, such a light is a great boon. If available, a number should be used at different points on account of the intensity of the shadows when all the illuminating sources are concentrated at one location. For work such as digging trenches, repairing roads, bridges, etc., not in the immediate presence of the enemy, acetylene outfits are quite useful. The individual generators should be such as can be carried by one or two men. For conducting a night march, a portable generator that can be slung on a man's back allows him to select or to follow a trail or road, and to guide the men in rear. This matter of keeping the men together during night operations is no mean task. Moon and stars are often hidden behind clouds or otherwise obscured. In marching along a road on a dark, rainy night I have had occasion to require my men to attach their handkerchiefs to the back of their

belt so the men in rear could tell where to go, or when to stop in order to avoid stepping on the men in front. A portable acetylene generator with a reflector forms a reasonable substitute for a small searchlight, and would be suitable for use by the defenders of a line of trenches or for use in other works of the offense or defense. For such purposes compressed gas tanks, with tubing, burners, and reflectors would also be convenient for emergency use.

When engaged in hunting deer by night in the Philippine Islands, small acetylene lamps are sometimes worn strapped around the head, with the light over one eye. The sights of the rifle are readily brought into line with the eyes of the deer; the eyes showing up like two fiery balls. This practice is not necessarily peculiar to the Philippines, but I mention it merely because I have seen it used by the army.

Electricity is, of course, the main source of illumination wherever it is available. Officers' quarters and the barracks and other buildings at army posts are ordinarily lighted by it. In manœuvre camps which last some time, and where power is available, it is frequently installed to light the tents and the company streets, picket lines, incinerators, etc.

Uncle Sam's seacoast forts, although ordinarily situated at or near large cities where current is available, most frequently have their own sources of power. This is logical, although not so economical. If the fort depended on the city for its current, it might at some vital stage in the enemy's attack be left without power to run motors, illuminate magazines, plotting rooms, etc. Not long ago I read where one of the European belligerents was so unfortunate as to have a fort deprived of current because of the destruction of the source of power located at a considerable distance from the fort. Some of our seacoast defenses have both commercial and local sources of supply, so that one acts as a reserve to the other in case of an emergency arising that would put one out of commission. A central generating plant at the fort would be the most economical local arrangement, but a single well-directed shot might paralyze the whole. To provide for such an emergency, a reserve supply is necessary, as indicated above. Where reserve energy is not already provided for in

other ways at seacoast forts, it is current practice to install 25 kilowatt gasoline generating sets at or near the batteries. On account of the development of these gasoline sets, the use of storage batteries in fortifications is being discontinued. These batteries were formerly used for supplying telautographs, as well as motors and lights, but are now employed only in connection with telephone systems.

Though not bearing directly on illumination, the following recommendations regarding power plants in fortifications are quoted from the 1906 report of the National Coast-Defense Board: (*a*) that the electrical energy used for fortification and defense purposes be furnished by an adequate steam-driven, direct-current central power plant, all machinery to conform in type to approved commercial standards; (*b*) that each battery or group of batteries be equipped with gas-driven or oil-driven direct-current generators, installed as a reserve to the central plant; (*c*) that the energy supply of searchlights be provided by self-contained units unless the searchlights are in close proximity to the central plant; (*d*) that the torpedo casemates be supplied with energy from independent sources for submarine-mine purposes; this arrangement should constitute an integral part of the submarine-mine defense; (*e*) that alternating current energy, when essential, should be obtained from the direct-current distribution system, using for the purpose a suitable converter; if, however, it is found more economical, this energy may be obtained from a separate alternator; (*f*) that the central-station output, when not needed for fortification service, may be used for garrison purposes, provided that the latter load does not require too large an increase in the size and number of units; (*g*) that, should the garrison service require an alternating-current distribution system, the energy should be supplied from the central plant, either through a suitable converter or from alternators installed for this special purpose in the central station; (*h*) that uniformity of types and accessories should be adhered to as closely as possible.

Before proceeding further with illuminating applications in the army, I shall give the rules formulated by the Board on Standardization of Wiring for Seacoast Batteries: (*a*) conduits should not be employed for local distribution in emplace-

ments where their use can be avoided; (*b*) all wires leading out from the emplacement switchboard should be exposed in so far as possible; (*c*) armored cable should be used for all exposed wiring, and lead-covered cable should be used in conduits; (*d*) all branch lighting circuits in emplacement distribution will be of No. 12 A. W. G. wire; (*e*) exposed wires will be supported on ceilings or walls with cable hangers, to permit the application of preservative coatings; (*f*) snap-switch and plugging-in boxes introduce more points where grounds may occur, and should be used only where they are absolutely essential; (*g*) a branch lighting circuit may carry a maximum current of six amperes; (*h*) all fixtures for inside or outside lighting about emplacements should be of approved water-tight types.

Due to the effect of alkalies on the lead covering of cable, concrete conduits are no longer being installed. Where the lead covering of cables comes in contact with the concrete, the alkaline waters tend to eat through the lead, allowing water to enter, which gives rise to grounds. I have here a piece of such cable that had been in place for 13 years. In this case, strap hangers were used, which caused the lead to lie against the concrete ceiling of one of our batteries. The upper part of the lead is eaten through, while the lower side seems to be in very good condition.

To eliminate as much as possible the trouble from grounds in the circuits of our seacoast batteries, a special marine type of fixture has been developed. As the condensation and other sources of moisture that are always present along the coast tend to rust or corrode exposed iron or steel, the fixtures are made of a bronze composition which casts and machines well.

In the rooms of our batteries the lamp fixtures are ordinarily attached to the ceiling, but where, due to low ceilings, this would interfere with the headroom, wall fixtures are employed.

To illuminate the gun platforms, or loading platforms, some batteries have the light fixtures in recesses around the walls, with additional fixtures and reflectors along a railing at the rear. It is difficult, however, to obtain proper illumination without having the lights shine in the eyes of some of the men. A sort of vertical plotting board is installed near the gun. This is illuminated by means of lamps in 15° reflectors. These lamps are of the 40-watt tungsten type, but commercial carbon lamps are generally

used elsewhere. Both the tungsten and the carbon types seem to stand up well under the shock of discharge of the big guns.

For illuminating the cross wires in telescopes and range-finding instruments, low candlepower electric lights are employed. The range scales are lighted by means of regular lights or by pocket flashlights. Mortar battery pits are usually provided with conical reflectors containing a cluster of lights. In such a case care must be taken that the shock of discharge does not cause the lamps to whip against each other, and so become broken.

In case of the failure of the regular sources of power, the magazines and other rooms of batteries may, in an emergency, be illuminated by reserve lanterns. These consist of a case containing several dry cells, with a small tungsten lamp and a reflector. They may be set on the floors, hung up, carried, or set in recesses prepared in the walls.

For the lighting system proper, direct current at 110 volts is employed. The gasoline generating sets mentioned above are wound for 115 volts, flat compounded. In the distribution the practice seems to be to limit the drop in lighting circuits to 5 per cent. and to 7½ per cent. in circuits feeding both motors and lights.

The lighting appliances already treated to perform their several functions in their own quiet way, but the real eyes of our forts are the searchlights. The sizes most commonly used are the 60 in. and the 36 in., although some 30 in. and 24 in. are still in service. The mirrors are ordinarily of glass, parabolical in shape, and with silvered backing. The ranges at which targets may be satisfactorily illuminated by a 60 in. searchlight are as follows: With very clear atmosphere, 10,000 yd. and sometimes farther; with average atmosphere, 6,000 yd. to 8,000 yd.; through slight haze or rain, 3,000 yd. to 4,000 yd.; in medium haze or gray dawn, 1,000 yd. to 2,000 yd.

Characteristics of searchlight arcs are as follows:

Size of light (inches)	Current (amperes)	Volts across arc	Size of carbons in inches (positive)	(negative)
24	50	48	1.0 by 12	0.75 by 7
30	80	50	1.125 by 12	0.875 by 7
36	130	60	1.25 by 12	1.0 by 7
60	175	65	2.0 by 15	1.375 by 12

For the 60 in. light both carbons are cored. The life of such a pair of carbons is about 5 hours.

In using the searchlights in cold weather it is advisable to heat and cool the mirror gradually, because rapid expansion or contraction may cause the silvering to flake. Elevating the light too much about its horizontal axis may cause hot particles of carbon to fall on the mirror. Similarly, if the beam be depressed too much the heat of the arc may injure the mirror.

When illuminating a target it is found that an observer at the light cannot see it as well on account of having to look through the diffused light. Better positions for the observer are below and to one side of the light. The searchlight can be traversed in azimuth and elevated or depressed by an operator at the light, but it is desirable to be able to manœuvre it from one or more points at a distance. This is accomplished by means of a searchlight controller, which is connected by means of a nine-wire cable with two motors in the base of the searchlight. Turning one of the controller wheels in a certain direction causes the searchlight to traverse in the same direction; turning it the other way traverses the light accordingly. Turning the other wheel causes the light to elevate or to depress, according to the direction given the controller wheel. The speed with which the light moves is determined by the rate at which the controller wheels are turned. Both traversing and elevating or depressing may be carried on simultaneously. By means of azimuth circles on the controller and on the base of the light, the searchlight may be pointed in any direction without having to go near it.

If the searchlight be located too close to the ground, the diffused light illuminates the foreground and discloses too much of the site. If located too high, a low-lying fog bank may render the light of no use.

The different functions that may be served by searchlights are treated below. The beam may be fixed horizontally so as to show up any vessel attempting to cross a particular illuminated strip or zone. It may be used as a roving or searching light in an endeavor to pick up or discover any ships within its range. An enemy vessel, having been discovered in this way, is given the attention of another light whose function is to illuminate the target for the rangefinders, while they determine its exact loca-

tion so the guns may open fire. To nullify the efforts of the enemy's searchlights, one or more of our own may direct their beams generally parallel to our front. This forms a screen through which the enemy's lights cannot be used to advantage. An enemy pilot trying to navigate his ship is considerably nonplussed or bewildered if a searchlight be turned full in his eyes. Here the effect is quite the same as we have experienced when the other fellow in an automobile has neglected to turn off his bright headlights when approaching us. Signalling may be accomplished by alternately showing and occulting the beam, by turning the beam on the water or on the clouds; or, by means of a shutter, flashing the dot and dash code.

The Beck searchlight, of which many of you have undoubtedly read, uses smaller carbons so as to cut down to a minimum the "shadow," or dead space, on the mirror, which is caused by the interference of the carbons with the light rays. The use of smaller carbons is made possible by resorting to greater current density. This can be accomplished on account of the fact that the carbons burn in an atmosphere of alcohol vapor, which cools them and also prevents rapid oxidation, or burning. The carbons are rotated to assist in keeping the arc properly centered. This whole arrangement gives considerably greater efficiency than is obtained from our lights that are at present installed; but developments are being made therein from time to time.

For use in field operations, small mobile searchlights are employed. The aim here must be to keep the weight down so as to allow of rapid and easy transport. Some sort of motor car or truck is the type usually encountered, although we have self-contained units that are animal drawn.

To supplement the use of searchlights, star shells, rockets, etc., are finding extensive fields. Star shells and rockets are generally fired from a special type of gun or mortar. They afford a bright light when they burst in the air. One type of rocket burns for a considerable time and is carried by a parachute, which opens when the rocket explodes. These are quite efficacious, and there is little or no probability of their being destroyed before they have served their purpose.

When firing at aircraft it is necessary to know what relation the path of the shell bears to the position or path of the target.

By means of smoke or flame compositions in the base of the projectile, its course may be traced day or night.

As having a slight bearing on the subject of illumination, I desire to point out, in closing, that, by the application of phosphorescent compounds, compasses and watches have their dials so treated as to make them readable in the dark. From the frequency with which night operations are undertaken in the present war, you can easily realize what a distinct advantage it is to be able to determine the time or direction without having to show a light.

DISCUSSION.

MR. L. C. PORTER: In connection with measuring the glare when you are looking towards the lamps, I have tried one method which seems to work out satisfactorily, though perhaps we do not have any definite units to set it down in. We set up a headlight and take out a distance to one side of it a small colored light, such as would be used in signals, and then move this colored light in towards the headlight, towards which we were looking from a distance of several hundred feet, until the colored light is lost in the glare of the headlight. Then we measure the distance from the headlight at which the colored light disappeared, due to the glare of the headlight. There was no doubt with the amber glass; you could get closer to the headlight with your colored light, and still see it, than you could with the clear beam of equal intensity.

In regard to the observer standing behind the searchlight, that makes little difference with a small searchlight, such as an automobile headlight or something of that sort. When you get into very powerful searchlights, there is a very appreciable amount of light thrown back into the observer's eyes from fog, and that reduces the ability to pick up objects.

DR. C. P. STEINMETZ: Recently I made some crude experiments by means of a small searchlight equipped with a tungsten lamp. With identical conditions as to the source of illumination and the arrangement of the searchlight, various colored glasses were tried in front of the lamp, first, a clear glass, then a slightly yellowish glass, and finally a bluish green glass, in order to get the effect of the short wave light. From behind the

searchlight it seemed that I could see about equally well with the yellow and clear as with the blue. By making observations to determine whether I could see objects which were inobviously illuminated I could not seem to distinguish a marked difference between the yellow and white, although the yellow seemed to be slightly better. My impression was that there was a decided advantage with the bluish-green because there is really less glare from the illumination of inert objects under the bluish-green light than under the yellow or white light. I do not think there would be in such a case any marked difference between yellow and the white because if the long wave lengths are varied there still remains the glare. When standing considerable distance in front of the light the bluish-green seems less glaring than either the white or yellow; however, at close range and slightly at the side, the yellow and bluish-green seem to be about equal as to glare, while the white is decidedly uncomfortable.

It is quite marked that inert parts were more distinguished with bluish-green than the yellow or white, but that was under favorable weather conditions where there are practically no flying particles in the air, which would give a marked advantage within a short range of 100 yards.

MR. J. L. MINICK: It may be of interest to know that experiments have recently been made in which amber glass is used as the cover glass for locomotive headlights. One of these headlights is now in service in the vicinity of New York City. This headlight is equipped with an incandescent lamp and prismatic glass reflector and gives about 2,800 candle-power at the center of the beam. The same type of headlight with clear cover glass and a lamp of slightly different design, giving some 700 or 800 beam candle-power, is also in use in the same service. The enginemen state that they experience much less discomfort when approaching the headlight with the amber cover glass although this headlight gives about four times the intensity of that with the clear cover glass.

THE SELECTION OF A STANDARD UNIT FOR COMMERCIAL LIGHTING.*

BY WALTER R. MOULTON.

Synopsis: The rapid advancements of incandescent lamps having rendered obsolete commercial fixtures that were formerly installed by a central station for its customers, the problem arises of selecting a new style of fixture or fixtures on which to specialize for commercial work. The different viewpoints of consideration are given and followed by detailed examples of individual cases. The summary shows how a decision was reached after giving due consideration to the various attributes of each style of unit, also the method of placing the unit in actual use.

A number of central stations have in the past made a practise of selling or recommending some one or two definite forms of commercial lighting for the majority of their customers, commercial lighting in this sense usually including the average stores, halls, showrooms, etc. The standard adopted has usually been a direct lighting fixture of efficient type in which attention has been given to proper distribution of light and protection of the eye from the direct glare of the filament.

With the recent advent of gas-filled, incandescent lamps, efficiency has been greatly increased over the former type of tungsten filament lamps. At the same time the size of the filament, that is, the total space taken up by the entire winding, has been greatly decreased and the intrinsic brilliancy of incandescent lamps for commercial lighting has reached a point where their use with open reflectors or with equipment that exposes the lamp to view has become prohibitive. At this time it is necessary for a central station, desiring to give its customer good service, to discard the old standard equipment. Experience and past practise have shown the desirability of selecting a standard lighting unit for commercial work. The adoption of such a standard does not necessarily limit the work that would be done with special equipment such as total indirect lighting or semi-indirect lighting, where

* A paper presented at the ninth annual convention of the Illuminating Engineering Society, Washington, D. C., September 20-23, 1915.

conditions are favorable and where results are desired different from the ordinary.

In selecting this standard unit a thorough study must be made of products available on the market. The fixtures to be considered must be efficient and must so distribute the light that most of it will fall where it will be useful. They must totally conceal the lamp from view and must diffuse the light; they must allow of easy maintenance, both in respect to cleaning and lamp renewals; construction must be simple, but rugged; appearance must be neat, not necessarily ornate; the manufacturer's production must allow a universal application for various size lamps and varying conditions as to ceiling height and size of establishment lighted. The reliability of the manufacturer is important. He must be able to produce the goods of uniform quality and in quantities to meet the demand. He must be willing to make necessary slight changes in construction that would improve some important feature of the fixture, such as to facilitate quick installation, easy cleaning, etc. If he at present produces but one or two sizes, he must be willing to make the line complete to fill the universal requirements.

Economic features deserve serious consideration. The first cost of the fixtures should be worked out on a uniformly comparable basis. This can very well be done by figuring the cost per watt of the fixture complete with proper size lamp. Of course, such a comparison would be slightly changed depending upon the comparative efficiencies of the units. As long as the efficiency of the unit is fair, a few per cent. difference in favor of any one style of equipment would not have much weight in deciding in its favor. Other features would far outweigh this one. The apparent comparative value of appearance or design of the fixtures is deserving of serious thought, especially from the merchandising or sales viewpoint. The fixtures must have features that will meet with the trend of lamp development, so that they will not need to be discarded in a year or two.

The following special points can be set down as requiring consideration. First cost of fixture; efficiency and distribution; maintenance; construction; appearance; adaptability to varying conditions; and merchandising loss, that is, depreciation that is liable

to occur in carrying fixtures in stock and handling and installing them.

Practical Application.—The Consolidated Gas, Electric Light & Power Company of Baltimore found itself confronted with the problem of selecting a standard commercial unit as outlined above. Several types of commercial lighting units, which are on the market and found among the advertisements in trade journals, were selected for consideration, keeping in mind the requirements mentioned above. The various physical features of each fixture were given consideration and one or two were very quickly weeded out on account of some especially glaring feature. One fixture, for example, seemed to have a wide range of adaptability, easy to maintain and fairly efficient, but its construction was very faulty in that the complete weight of the fixture was suspended by three thumb screws. Another fixture seemed to be of very good construction, easy to maintain, offered a wide range of adaptability and seemed efficient, but its appearance was awkward and it was subject to excessive breakage.

Finally out of the number of fixtures considered two types were selected as offering the best possibilities for a commercial campaign. The first fixture, unit "A" Fig. 1 is an acorn shaped, enclosing globe. The upper shell is equivalent to the shell of an acorn and of very heavy density opal glass. The lower shell is equivalent to the acorn itself, in about three-quarters of the full height of the globe and of medium density glass. The lower globe can be obtained in either plain or etched glass. The two globes are held together by a joining ring, hinge and thumb screw. Ventilation is provided by a 1-inch hole in the bottom of the lower globe, openings around the connecting ring and also in the hanging shell at the top over the socket. The lamp hangs pendent so that the filament is about in the center of the globe. The entire unit is suspended by a single chain hanger. This unit is fairly efficient and the light distribution is such that the greater part of the total light flux is in the lower hemisphere. The typical distribution of light being as shown in Fig. 2. This style of fixture can be had in two sizes, the smaller of which is especially adapted to the use of 100-watt and 200-watt gas-filled tungsten lamps; while the larger size could be used with 300-watt, 400-watt and 500-watt lamps.

The second fixture, unit "B," Fig. 3, has an upper reflector section of a flat opaque white disk, below which is suspended a hemisphere of medium light density glass. The bowl is about one-half the diameter of the disk. The lamp is hung from the center of the disk so that the filament is about in the center of the hemisphere. The hemisphere is suspended from the upper section by means of three links. The entire unit may be placed directly at the ceiling or suspended by a chain hanger. There are several different designs and sizes of this unit available.

Styles of the standard units having been determined upon, their application will be according to standard good lighting practise. The selection of the individual fixture for each installation depends largely on the individual selection of the owner, assisted by the recommendations of the salesman.

Having selected a standard unit that can be applied to commercial work, the selling prices of the units, with various sizes of type "C" lamps from 100 to 500-watt inclusive, are tabulated for the use of the salesmen in selling lighting equipment, Table I. The salesmen are given also tabulated data and information pertaining to the application of these standard units for commercial lighting. For each individual size of lamp the average spacing is given for both medium and strong illumination. At the same time the range of mounting height for that spacing are given by stating the maximum and minimum mounting heights advisable. An example of the manner in which this is applied is shown by the accompanying table. This table which was compiled for the application of unit "A" shows in the first column the range of lamp sizes covered from 100 to 500 watts. In the next two columns is shown the average spacing allowable for each individual size lamp for both medium illumination and strong illumination. In the next three columns are data pertaining to mounting height of the globe. The center column gives the recommended mounting heights under average conditions. The salesman is allowed certain leeway to apply his own judgment, but definite limits are set beyond which it is deemed inadvisable for him to go. Therefore the two columns showing maximum and minimum mounting heights are included. In the last column are the selling prices of the unit installed complete, with a lamp.

Fig. 1.—Acorn shape inclosing globe.

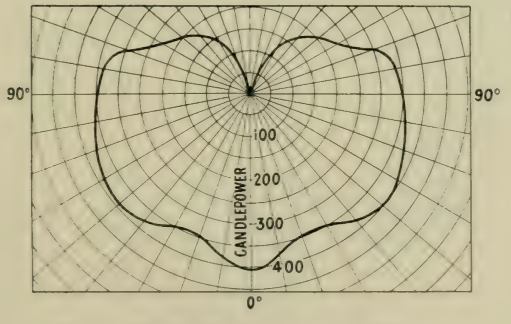


Fig. 2.- Typical distribution curve of Fig. 1.

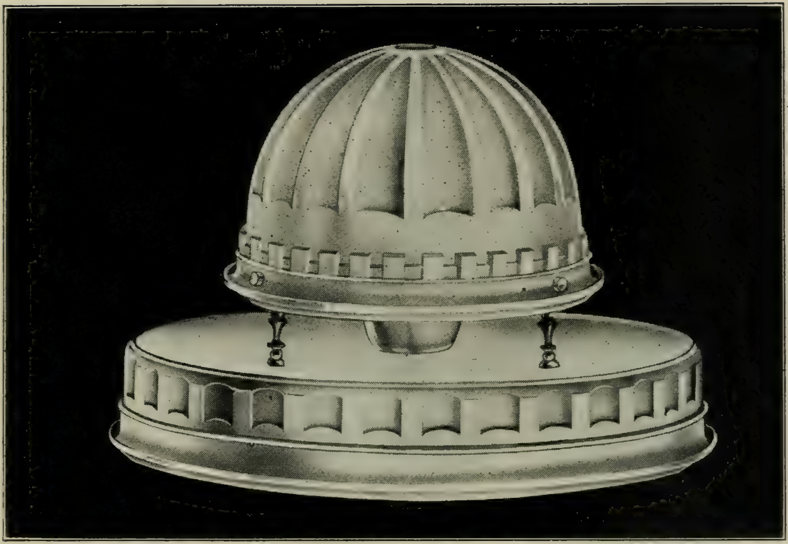
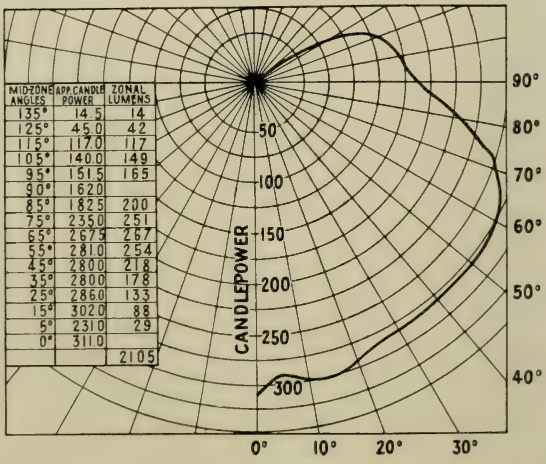


Fig. 3.—Reflector disk above a hemisphere of medium light density glass.



MID-ZONE ANGLES	APP. CANDLE POWER	ZONAL LUMENS
135°	14.5	14
125°	45.0	42
115°	117.0	117
105°	140.0	149
95°	151.5	165
90°	162.0	
85°	182.5	200
75°	235.0	251
65°	267.5	267
55°	281.0	254
45°	280.0	218
35°	280.0	178
25°	286.0	133
15°	302.0	88
5°	231.0	29
0°	311.0	
		2105

Fig. 4.—Typical distribution curve of Fig. 3.

With this information at hand the salesmen of lighting equipment canvass the various districts to which they are assigned, calling upon all storekeepers, selecting especially those where antiquated lighting equipment is in use, and leaving those with fairly modern equipment till later.

To assist the salesmen in their work photographs have been taken of a few typical installations of these standard units. Illustrated circulars are mailed to store owners and shop keepers with return post cards attached. All the information received in this way is, of course, turned over to the salesman to follow up.

The ease of adapting these standard fixtures to practical requirements materially simplifies the commercial lighting work of the central station, as the figuring of a large installation becomes merely the repetition of a simple problem.

The adoption of such a standard unit is the means of rendering good service to the customers of a central station. It relieves them of the necessity of studying the merits of a number of different styles of fixtures and the possibility of their unwittingly selecting an inefficient or impractical fixture. It is also very good business from the merchandising or sales standpoint.

TABLE I.—COMMERCIAL FIXTURES, UNIT "A"

	Spacing of lamp		Mounting height			Selling price with lamp	
Size of lamp	Medium illumination Feet	Strong illumination Feet	Minimum Feet	Average recommended Feet	Maximum Feet	Plain globe	Etched globe
100-watt ...	10	9	8	10	12	$7.60	$11.00
200-watt ...	15	13	9	10	12	8.60	12.00
300-watt ...	19	17	10	12	14	11.00	14.50
400-watt ...	22	20	12	14	16	12.00	15.50
500-watt ...	24	22	14	16	18	13.00	16.50

DISCUSSION.

A. B. SPAULDING: For some years central stations have advanced the use of standard lighting units of some type or other. We all remember the old alternating current enclosed arc lamp and the incandescent cluster, which many central stations furnished free to the customer in years gone by.

As Mr. Moulton has said it is only through the development of the type "C" lamp that we have been forced to change from the old units mentioned above, and with the doing away of these

old units, it becomes necessary to make the fixture for the gas-filled lamps a sales proposition.

What unit or units to adopt as standard is a very important question for all central stations, but I believe the number should be limited to not more than three types. Two of these to be of the medium or better class fixtures and a third to be of the cheapest material and construction, as would consistently go with good service.

This third lamp should not be promoted to any great extent, but should be held more or less in reserve to meet the competition of unreliable contractors or electricians take advantage of a central station advertising campaign and render poor service to the customer by selling an article which would not give good service.

It is not the intention to convey the impression that the central station want this field, for exactly the reverse is true. All reputable contractors are usually asked to co-operate in a central station campaign on standard or non-standard fixtures, which are efficient and will render good service to the customer and assistance is given them in every way in the sale of their own goods.

I have heard several people say that it is a hard proposition to get a storekeeper to adopt a unit similar to that next door. To my mind the contrary is the case, as illustrated by the use of gas arcs and gas fixtures, the arcs in particular being practically identical from door to door.

With this in mind a salesman should have no difficulty in placing fixtures for the gas-filled lamps where this objection arises.

By presenting to the customer too varied a line he is apt to become confused and make his choice from the standpoint of beauty rather than efficiency. By confining the number of fixtures to one or two standard fixtures and possibly a third to meet the competition of the unreliable stores, as mentioned above, the keeping of sales records and stock will be simplified and a real service will be rendered to the customer.

Mr. W. A. Durgin: In the introductory paragraphs this paper directs attention to the excessive brightness of the newer mazda lamps, but in the list of special points requiring consideration in the choice of a standard unit there is no mention of

brightness of visible source. It would seem that a fair-sighted public service policy must place such brightness questions well up in the list, probably second to nothing but first cost of unit.

True, a considerable demand for extremely bright glassware does exist, but it is confidently expected that a few months experience with the eye-strain from such units will turn the customer not only against the particular equipment in question, but also against the party who supplied it. Admitting that the present public taste requires units brighter than the illuminating engineer's experience can approve, it is still possible to influence the customer's choice toward better practise and to reduce the installations of the more glaring units. The choice of a standard combination offers a most important opportunity in this direction.

Mr. Robert P. Burrows: The sentence on the last page of this paper—"To assist the salesmen in their work, photographs have been taken of a few typical installations of these standard units"—recalls to mind some stereoscopic pictures that I have seen of lighting installations. The flat photograph does not give the idea of depth, but with the stereoscopic photograph, depth is added to the picture, which gives a very good idea of the distribution of illumination. For instance—a stereoscopic picture of a machine shop was shown, and attention called to a drill press some distance down the aisle, giving a good idea of the general distribution of illumination about that part of the floor. A second stereoscopic picture, taken close to the drill press, showed that all parts of the machine were well illuminated. It occurred to me in reading this paper and also in reading Mr. Spaulding's paper that an inexpensive little outfit could very easily be worked up for the salesman's use which would materially assist him in showing lighting installations with stereoscopic views and which would better show the distribution of light.

Mr. S. B. Burrows: Mr. Moulten's paper shows that we are on the right track insofar as the recommending of a unit for customers is concerned. Without question the type "C" lamp is better enclosed in a bright glass or glass having a high brilliancy than no glass at all and in choosing a fixture which we can recommend, it must necessarily be a compromise between the illuminating engineer's ideal and actual commercial possibilities. As to

a standard fixture being advisable, I believe that is open to question. In one of the towns in Jersey there has been campaign in which one fixture was presented to the customer and a very important point has developed, namely, the fact that there ought to be more than one fixture; and now the lighting company has in process of planning a campaign offering four standard fixtures for gas-filled lamps. It is believed that by selling these fixtures many poor direct lighting systems will be eliminated and the customers' lighting installations at least materially improved.

Mr. Z. M. Hyer: The term "standard fixtures" to me does not mean anything; I think each company has set its own standard. I have had some little experience in putting a standard fixture in the city of Brooklyn, and also one in the city of New York and neither of them was of the same type. The fixture must be selected to meet the local conditions. I have never seen any fixture that would be applicable to every line of business. A fixture might be adaptable to a shoe store that would be entirely out of place in a millinery store, or some other line or business.

Mr. G. B. Regar: It is to be regretted that commercial activities permit unprincipled firms to bring out cheap and inefficient lighting fixtures to combat the central station which has a lighting fixture campaign before the public. Some people naturally will be fooled, but I cannot agree with the suggestion that the central station should have a cheaper fixture just to beat or compete with the other fellow, because the consumer suffers in either case, and the central station has stooped to do just what it condemned in the electrical contractor. Regarding the standardization of lighting fixtures—I can't see that this need cause any worry. As a rule, only the poorly lighted shops are the prospects of the central station lighting salesman having a fixture proposition, and the substitution of a more modern, ornate and efficient fixture must be welcomed by both the consumer and the central station. The man who wants individuality, as a rule, can afford to pay for it. As to standardization, the lamp question is more of worry than the fixture. The fact that the type "C" lamp is not made in the smaller sizes, and is not a free renewal; and furthermore that only the larger size tungsten lamps are free renewals, is the means of spoiling many heretofore fairly

good lighting installations. One often sees a modern store fixture equipped with either opal or prismatic reflectors, where the consumer has replaced three 100-watt tungsten lamps with two 100-watt gas-filled lamps. The fixture is unbalanced. Or perhaps the customer has substituted three 100-watt tungsten lamps for one 200-watt gas-filled lamps, or four 60-watt tungsten lamps for two 100-watt gas-filled lamps. In both cases the lamps hang below the reflectors and are within the range of vision and are exceedingly objectionable. Of course, they serve the purpose of economy as to energy consumed, and at times as to cost of lamp maintenance, but at the expense of the esthetic and psychological effects.

Mr. A. L. Powell: One of the speakers mentioned that a great deal of improper lighting results when 100-watt gas-filled mazda lamps are substituted for 100-watt vacuum type lamps. In this connection it might be well to point out that in designing the new lamps particular attention was paid to the position of the filament. In the first place the bulb is somewhat smaller than that of the vacuum lamp. The filament is so placed as to give approximately the same light center length for the two lamps, but the filament barrel, or space occupied by the light source, is much smaller in the gas-filled lamp; therefore the incandescent material is not as low in the bulb as in the old type. If the vacuum lamps were used in reflectors of the proper size, *i. e.,* large enough to hide the filament at ordinary positions of viewing, the new lamps will also be shielded. Of course, where the lamps are used bare, or in too shallow or too small reflectors, they are subject to criticism.

Statistics show that the 100-watt lamp is the size most generally employed for the class of lighting under consideration; that is, the ordinary small store, the average office and the like. This lamp in the new form does not prove objectionable for direct lighting when properly used. I have in mind a large sales office equipped with bowl-frosted lamps in bowl-shaped prismatic reflectors, 8¾ inches in diameter, 5¾ inches deep, etched on the inner surface. This arrangement gives very satisfactory illumination and, as the ceiling and walls are a pure white, contrasts in brightness are not extreme.

Another speaker called attention to the fact that there are distinctions in the classes of stores, and that one type of unit would not meet all the needs. I agree with him perfectly; yet it must be remembered that there are hundreds of cases found in every city, such as the ordinary small store, where the proprietors cannot afford to have distinctive fixtures and just such a standard equipment as Mr. Moulton has described meets these conditions. The higher grade stores certainly want something different—something more artistic—and I know that any central station such as the one Mr. Moulton is connected with would be only too glad to cooperate with these customers in designing a special layout and would not think of selling the distinctive store one of these standard fixtures.

Mr. T. W. Rolph: We have had a paper delivered at this convention describing a semi-indirect bowl considerably denser than the types of bowls in ordinary use, and this paper* was highly commended in the discussion. It seems to be the nearly unanimous opinion of the engineers working on lighting of this general character that dense glassware is desirable for any form of semi-indirect lighting. More broadly, it may be said that for any form of lighting it is desirable to interpose between the light source and the eye some dense medium. As the ordinary directions in which the eye looks at a lighting unit are from the horizontal up to possibly 30° above the horizontal, we may expect as a criterion for good eye protection with any lighting unit, that the candlepower values of the lighting unit between the angles of 60° and 90° from the vertically downward direction should be low. In other words the candlepower values from the unit in the directions from which it is viewed in the ordinary installation should be low. Neither of the two units described in this paper has this characteristic and neither of them gives adequate eye-protection according to the ideas generally held by engineers to-day.

The difficulty is that in general there is too much design work with no regard to the protection of the eyes, for it is easy to follow out principles of good eye protection if they are appreciated by the designer. For example, the acorn shape shown

* Durgin and Jackson, Semi-direct Office Lighting, etc., TRANS. I. E. S. vol. x, p. 690 (1915).

in the paper could, by a slight change, be made to embody the principle pointed out above. The upper half of this unit is of heavy density glass and the lower half is of light density glass. Since the upper half is shallow and the lower half deep, the lamp filament comes below the upper half, and consequently light density glass is interposed between the lamp filament and the eye. To remedy this, I would suggest that the unit be essentially turned upside down with whatever slight changes are necessary for appearance reasons. The upper half will then be deep and should be of heavy density glass. The lower half will be shallow and of light density glass. The lamp filament will come above the dividing line between these two and the heavy density glass will be between the lamp filament and the eye at all ordinary angles of vision.

A. O. DICKER: In the selection of a standard lighting unit the central station can not exercise too much care. I believe it is the policy of most central stations to pay their salesmen—at least in part—commission on the sale of the company's standard equipment. This means that the salesman will sell standard equipment wherever possible.

People are inclined to look to the lighting company for suggestions as to fixtures and to take their unbiased recommendation. Therefore, the central station is, in no small way, responsible for the lighting standards of the city.

From experience I have had with central stations, I believe it to be policy for the company to establish standard units for various classes of service; for instance, a standard store fixture, a standard factory unit, a standard exterior lighting unit, etc.

We can all remember when practically all of the fixtures installed in Chicago by the lighting company were four-light clusters. These were at that time the standard fixture. Since then the larger unit direct-lighting fixture has been installed in great numbers. At the present time these fixtures must be changed, this time for the type "C" lamp.

It is not good practise—in but very few instances—to simply change the lamps from type "B" to type "C." It means the fixtures must be altered or new fixtures installed. It means, too, a change from direct lighting to semi-direct in most cases.

MR. NORMAN MACBETH: One important point in this paper that has not been specially referred to, is the price at which the fixtures are sold. These prices are such as to not upset the trade. I do not feel that either a gas or electric company should pose as the sole purveyor of lighting fixtures in any particular district, or that they should endeavor through low prices and free service to take all the business. In every city there are men who have been in the fixture business for many years. The company policy should consider the cooperation of these men and should not tend to take the business from them. I recall an excellent method, from a personal experience some years ago, in buying a gas range. I did not go to the gas company; I went to a retailer I knew, and he told me that if I would take any of several styles of ranges approved by the gas company, the company would connect the range free of charge. He added that the company would pay him a small commission as well, thus encouraging the use of approved appliances. I believe that if the gas and electric companies would consider the man who has been in the lighting business for years, as a manufacturer or a dealer, if they would assist that man and advise him of the kinds of fixtures approved for use on their circuits and thus extend the opportunity for cooperation, that the company would get that which it is most interested in—a greater use of its product—and better work would be accomplished.

It hardly seems right for a gas or electric company to set itself up as the sole agent and purveyor of light. A few inexperienced salesmen and one or more near-experts, backed by the prestige of the lighting company, sometimes endeavor to take the business away from the men who, in the past ten, fifteen or thirty years have been the sole source of information and supply, and say "We want all of this business; you are an incompetent; we are going to inaugurate a big advertising campaign and you are to remain in ignorance; we don't want your help."

Isn't it conceivable that if the interest of these dealers were considered, and they were permitted to do their share in facilitating delivery in a campaign, that more and better results would be secured?

Standardized fixtures at the prices here shown are not likely

to antagonize the trade and are certainly a step in the right direction.

Mr. H. T. Owens: The standards shown by Mr. Moulton are a step backward and show that direct lighting is coming back. These commercial units are something with which to beat the gas arc lamp and will not provide good lighting.

Mr. W. R. Moulton (In reply): This paper deals entirely with commercial fixtures for the average conditions. It states that the particular central station is consideraing lighting fixtures to cover such conditions. As soon as a customer expresses a desire to divert from the average there is a larg selection of other fixtures to show him.

Mr. Spaulding spoke of the large possible selection of lighting units. The company is not limited to one or two fixtures entirely. These standards are merely for the average customers, others will be handled according to their special conditions. Should the contractor secure the same fixtures as the standard adopted by the central station there will be no harm done as the work will be along the same line, and his cooperation may be welcomed. The selling prices of the standard units are fair and any contractor can sell them at the same price and make a fair profit. If he desires to cut the price on this unit and undertake a special campaign to get the business, it will only add to the total result of the central station campaign.

Mr. Durgin spoke of the brightness of the source of light with these standard units. In selecting the units an attempt has been made to adopt one that will be adaptable to the various conditions and sizes of lamps. Both units mentioned in this paper are available in several sizes and the size of the unit recommended with any lamp will be such that the brilliancy is not sufficient to be offensive to the eye.

Mr. S. B. Burrows spoke of the necessity of several fixtures. As mentioned previously, if any customer does not desire a standard fixture, there are many others from which to select.

As Mr. Macbeth pointed out, prices on the standard fixtures are such that they are fair to the customer, and to the dealer or contractor. We are not trying to eliminate the dealer or contractor from the business, but at the same time we wish our customer to receive a good practical fixture at a reasonable price.

Exception must be taken by Mr. Macbeth's statement regarding in experience of a central station man. It is true that central stations in general are only recently going into this work, but the majority of the men in this work have had considerable practical experience. In the past the central stations were negligent, but in the last few years they have been studying lighting problems thoroughly and aiming to give their customers best results. The lighting department of the central station is confronted with a variety of problems daily, whereas the dealer or contractor may only meet these problems once a week. Therefore, the lighting departments of the central stations are rapidly learning how to handle each individual class of work.

Mr. Rolph assumed that the filament might be seen in unit "A". That is not the case. The globe is light enough in weight to allow good efficiency, but dense enough to prevent the filament or a spot from showing.

The lighting salesman working on a salary and commission will hardly instal the standard units where something better would be advisable. His work is more likely to be governed by the commission he is to receive and this of course is greater on a higher priced fixture. There is always this incentive for the salesman to induce the customer to instal the best fixture possible.

For the central station to own and rent lighting units would indeed be a bad policy. There are many reasons for this, but one sufficient reason is that they would soon find themselves with a large stock of second-hand fixtures. When a customer changes his lighting equipment, it is for his own benefit; the fixtures are on his premises and he should purchase them the same as he does his other store equipment.

Mr. Owens suggested that the adoption of these units was a step backward. This would hardly seem to be the case, for these standard units are representative of the lowest class of fixture to be sold. When compared with the average commercial installation to be seen in all cities, they are a great step in advance. True the units are rather bright, but not enough to be offensive.

THE ARTIFICIAL ILLUMINATION OF INTERIORS AS RELATED TO ARCHITECTURE AND DECORATION.*

BY DAVID CROWNFIELD.

Synopsis: This paper is an exposition of the capacity of artificial light to model sculpture or architectural members, and illuminate painting or decorated surfaces, together with a discussion of the effect the directional angle at which light falls has on objects in the illuminated field and also of the effect of the color quality of artificial light on objects and surfaces which it illuminates. The views of interiors used to illustrate this paper are such that they include the artificial lighting of certain historic interiors abroad, also certain recently erected edifices in overseas countries illustrating the progress of the art of illumination in those countries, and also certain recent installations in this country with which the author of this paper has been directly concerned and is consequently directly responsible therefor.

Architecture, decoration and artificial illumination are allied arts. Research work carried on in the field of illumination within the last decade has only just begun to show the relation of this latter subject to the two former ones. Further study of this relationship promises much for the future development of the art of illuminating engineering.

The purpose of this paper is to indicate some points of relation between architecturally and decoratively treated interiors and illuminating engineering, in so far as the artificial illumination of these spaces is concerned; also to indicate some of the various features which are inherent in problems of this character, and to discuss the relation of these features to each other, and to some of the more ordinary artificial illumination problems of to-day.

To light a space so it can be used for the purpose for which it was designed, to distribute artificial light evenly throughout any space, or to distribute it extensively or intensely from points of distribution, these are the fundamentals of illuminating engineering. Consideration of these factors so far has been mostly from

* A paper presented at the ninth annual convention of the Illuminating Engineering Society, Washington, D. C., September 20-23, 1915.

the point of view of light in its effect upon a so-called working plane, that is to say, upon a surface of two dimensions; and the solution of the problem has been expressed as such. Where the problem has been a complex one, the effort has generally been so to resolve it into an expression that the solution of the problem could be expressed in a curve or in terms representing a surface of two dimensions. A broader view of illuminating engineering compels us to recognize that the proper use and distribution of artificial light and color is neither disjunctively an art or a science, but conjunctively is both.

Beyond the field of really primary problems on which the major part of the practise of the illuminating engineer has been concentrated for the past decade, lies the vast and complex region of the effect of light and color upon architecture or objects of three dimensions; upon painted walls and architectural members, or colored surfaces of three dimensions, by which are meant walls having receding planes; upon decorations and pictures, which are painted representations of surfaces of three dimensions; and of the reflex action which all these have upon man's mind, which one may call a fourth dimension that has to be taken into account.

It has become man's habit to surround himself, according to the state of his development with objects of beauty, architectural, sculptural and decorative; and it is one of the functions of the illuminating engineer to discover the qualities of artificial light, and artificially produced color, and to use them in such manner as will stimulate and develop man's imagination and his interest in whatever there is in the beautful in his surroundings, either at his work, in his home, or when abroad; for upon his cognizance of these things, particularly those he comes in contact with under artificial light, depends much of his ordinary every-day, natural pleasure in life.

The fundamental principle of all artificial illumination problems lies within the province of esthetics, and the solution of all problems is enveloped by the old adage that "Light illuminates painting and models sculpture." Under painting may be grouped all decorated or plain surfaces of two dimensions. And under sculpture may be listed all other subjects of three dimensions. Granting the above functions of light from the physical stand-

point, under one or the other or both of them can be grouped every illumination problem with which the architect, designer, painter, illuminating engineer or layman may have to do; for a ray of light expresses equally the beauty or quality of form whether falling upon a sculptor's masterpiece, an order of architecture, or a modern stairrail spindle revolving on the turner's lathe, it expresses equally the quality of decorative form and color whether falling on a Gobelin tapestry, a modern Turkish rug, or on an inexpensive wall paper in an humble artisan's home of to-day.

Light falling on surfaces of two dimensions illuminates them, falling on objects having three dimensions it models them. Light falling on an architectural member will cause it to cast a shadow on what is below and behind it, or, if the light is below any horizontal plane, above and behind it. If the receiving surface is a flat one, the shadow will express the form of the object casting the shadow; if the receiving surface is rounding in form or is one of receding or projecting planes the shadow will express in part the form of the receiving surface; if both objects are curving in their surfaces or angular and curving, or contain curves of double flexure, the shadows cast will be extremely subtle in their nature. It is the province of the illuminating engineer to so locate the light outlets, assign the quantity of light at each outlet, and arrange the distribution of light from each of these, that the architectural members or decorations in any interior will be adequately expressed by the artificial light falling on them that their shadows shall not be obliterated, or ugly, or false, or distorted, or hard and inartistic.

When light falls on a painting or decoration, it falls on a surface of two dimensions. An artist by his talent is able to create the third dimension of depth in his picture; if he is a genius he may create what may be called a fourth, which lies within the domain of psychology. This feature may be destroyed by poor and particularly by overlighting. The light in a room containing pictures should be so located that it will *adequately* illuminate the picture or pictures contained therein; it should be so located that, if possible, it will do this without coming into the range of vision, and that it will not overcast the shadow of the surrounding frame

or shadow box, if the picture has one; it should also not be placed in too close proximity to the surface of the picture, for if that be painted in broad, heavy strokes the artificial light will cast shadows of these, or it will catch on the raised portions of the brush strokes and over illuminate them, and make false high lights in the picture, and so create an actual third dimension and introduce features the artist did not intend or destroy the balance of the picture.

The light falling on a picture or decoration should be so controlled as to location, quantity and brightness that no object in the surrounding field is more brilliantly illuminated than the highest light in the painted picture, for surface brightness of surrounding objects should never be allowed to contest with a picture for the interest of the retinal activities of the eye. This does not mean that a room or space shall not be brilliantly illuminated in parts, but is a rule whose rigidity permits of no infraction so far as the visual field immediately embracing the picture or decoration is concerned.

In a room or space containing modelled plaster enrichment, or architectural members, in proximity to painted decoration, if we increase or decrease the quantity of light falling on them, it will affect the architectural members or plaster enrichment more than it will the painted decoration, for the surface brightness of both will be equally increased or decreased, and, while the light and shadows in the plaster enrichment will be increased or decreased in contrasting relation to each other, owing to the law of contrast, this will be greater in the architectural members than in the decoration which has but painted lights and shadows. This statement is based upon the assumption that the outlets are properly placed to cast the shadows of the architectural members agreeably and in a manner to express their form, and that the color quality of the light is such as to preserve a true balance as far as the color values in the painting or decoration are concerned. If one changes the color quality of artificial light it will affect the painted decoration more than it will the enriched and modelled plaster work, for every picture or decoration is supposedly a balanced color scheme with one dominant color or tone. Changing the color quality of artificial light falling on a picture or decoration to

one other than that under which it was executed, upsets the balance of the color scheme and thus destroys the harmony of color intended by the artist. No such result occurs as far as the enriched plaster work or architectural members are concerned, if these be not colored; if, however, these be colored, they will be affected more than the picture or decorations are, for the color on plain spaces and architectural members is usually flatter than that on paintings and decorations, reflects less light and consequently absorbs more of the impinging colored light and so is affected more.

Aside from theatres, auditoriums and ball rooms, the color scheme of most rooms is determined by daylight, by which I mean its color quality when the sun is not less than 30° above the horizon at sunrise or sunset and the sky normally clear and not overcast. Frequently such rooms become more agreeable when a slight glow of early evening sunset comes in; while exactly the reverse occurs if the day becomes more grey than normal. If one places side by side in a row, and in the order named, a carbon filament, a tungsten filament, a gas-filled tungsten lamp, and a mercury-arc lamp, there is obtained about the exact order in which these sources pleasantly affect a color scheme into which they have been introduced, the carbon filament lamp being at the top. If any architect or decorator is shown an interior comparatively lighted by these different light sources, and asked to state his preference he will instantly pick out the one illuminated by the carbon lamp. The reason for this lies in the fact that the yellow light of the carbon lamp added to any of the other colors and variations of these, while it may destroy their real color value, leaves them within the range of agreeable color sensations, while the light from any of the other artificial light sources named, modifies all the colors in a manner that may leave them distinctly less agreeable sensations than they are under daylight or under the light from a carbon filament lamp. Satisfactory artistic results in the handling of such sources depends on their being enclosed in color modifying light transmitting media that will bring their light into the range of agreeable color sensations. Such media should, however, have such transmitting qualities as will preserve the efficiency of the light source.

The effect of the location of the artificial light source or sources upon architectural members in any interior space is of very great importance. Conceive, for example, a room whose side walls contain pilasters at regular intervals, or if it is of simpler character, recessed spaces; and further conceive the walls and architectural members to be done in one color of the same tone throughout. It is not at all difficult to conceive of artificial light outlets being so located in such an interior as to cast no shadows whatever from the architectural members. Or one may easily conceive of their being so located that the shadows of some of these members will be false, and of some forced, by which is meant that the light will be too close to them and the shadows hard. In either of these cases the artistic reason for the introduction of the pilasters will be defeated. And in the last two cases the result will be extremely inartistic and unsatisfactory.

Again conceive a ceiling which is divided by beams into coffers, there being three coffers next to each wall and one in the center, or nine coffers in all. Such a ceiling might be over the dining room or living room of a private house, or over the reading room of a public library, or over almost any space in a private or semi-private, or in a public or semi-public building. It may be square, or one axis may be longer than the other. If it be square and the beams cross each other in a proper architectural division, it will be a simple matter to place the outlets at the points of intersection of the beams. If, however, one axis is larger than the other, the situation is more complex. Suppose an outlet has been placed in the center panel and one at each intersection of the beams, as this is a treatment which is generally given—the result will be that unnatural shadows will be cast from the center light source towards the wall by the beams which follow the long axis of the room. The distorted and false shadows thus cast will be very objectionable and can only be obviated by side wall brackets so placed as to cut out the objectionable shadows. It is obvious from this that the location of the light sources in any layout bears a direct relation not only to the distribution of the light but also to the proper expression of the architectural features of the room in which they are placed.

The effect of the location of the light source upon painting and decoration or colored surfaces in the surrounding field may be illustrated by returning to the previous simile of a room whose side walls contain pilasters at regular intervals, or of simpler character with recessed spaces. In the former case conceive the ceiling and pilasters to be done in tones of cream color and the panelled spaces between the pilasters to be done in a sage green or some other color distinctly darker than the pilasters. If a single outlet be placed in the center of such a room, regardless of whether it be square or rectangular in plan, it necessarily follows that the centers of each wall space directly opposite the light will be lighter than the portions towards the corners, and as the angle of the impinging light becomes more acute as the corner is approached, the color will become deepened. This is due not alone to the added distance, but it is also due to the irregularities in the surface which reflect the impinging light away from the beholder's eye, leaving the actual colors on the walls towards the corners less modified by the light falling on it than occurs towards the center of the wall spaces. While such a result is not at times undesirable it is to be avoided as much as possible in the treatment of rooms of a public or semi-public character, where a general distribution of light is desirable and should be attained.

There is another aspect of artificial illumination requiring consideration, namely, the use of artificial light in a so-called decorative manner. From what has been said of the capacity of light to illuminate decoration and painting, and model architectural members, and of the manner of handling artificial light so that it may best fulfil these functions, it is obvious that this does not permit of a large number of small individual units to mark the outlines of various architectural members in any interior space. Such a use of light units brings them so close to objects in the surrounding architectural field, with resulting distorted and awkward shadows, that the objects are not truly and artistically represented. Artificial light units placed in the manner above referred to should only be used exteriorly for advertising purposes to display the outlines and points of a building.

There is a physiological aspect of the present theory of vision that should be taken into account in considering the relation of

artificial light to architecture and decoration. Accepting the theory that it is the function of the rods and cones in the seeing forces of our eyes, to make selective presentation to the brain centers, of light and form and color, and that the rods respond to light, by which is meant white light, and grey when that is the result of a mixture of white and black, or of a balanced true grey when it is composed of other colors, and that the rods respond to form when that is not enveloped in color, while the cones convey to the brain centers all sensations concerned with color. It is at once evident that the different functions thus performed bear a very direct relation to the artificial illumination of interior space.

If an interior, such as a church of the colonial type of architecture, be decorated in tones of grey with the color inclining visibly but not strongly towards say a bluish grey, so that one regards the church as being decorated in grey but is at the same time aware of its bluish cast, it often appears that spaces, when they are so artificially lighted, give a result which is extremely unsatisfactory. The color sensation seems to oscillate between grey and blue. Those portions of decorated surface adjacent to artificial light sources seem to be a true grey, while portions more remote, and particularly those in corners become bluish violet in color. A person sitting in such an auditorium for any length of time becomes extremely restless, and very much more so under artificial light than when the place is lighted by daylight. This phenomenon is due to the fact that the plus of yellow in an artificial light source carries the grey color of the decoration nearest adjacent to it more towards a true grey in which no particular color is a dominant, throwing this portion of the wall into the range of sensations to which the rods respond, while the corners and more remote parts which partake of a distinct color value of bluish violet are carried into the range of sensations to which the cones respond. Between these two extremes is a running range many parts of which are extremely difficult to assign as either grey or color. I can find no solution of this difficulty other than that it is the effort of the rods and cones or seeing forces of the eye to pick out from this intangible field and convey to the brain that which it is their especial function to perform

that causes the restlessness of a person sitting under such a color scheme. Trouble with grey color schemes usually occurs where there is an over plus of bluish violet or reddish violet in the color scheme. The satisfactory solution of the trouble often devolves upon those having charge of the lighting scheme as it does not appear until that is a working installation. The solution of the difficulty, if possible, lies in the selection of a proper quality of light transmitting media, and proper distribution of the artificial light so that the grey wall decorations will be brought to a proper balance by the artificial light falling on them throughout their surface.

The selective functions of the rods and cones of the eye, in bringing to our consciousness form and color, is an exposition of the law of the conservation of energy that is too seldom regarded in the artificial illumination of any piece of work, for the true apprehension of any object by means of the organs of sight may be regarded as a piece of work to be done, and it is apparent that if one divides the work or operation of seeing any object between two apprehending functions one has divided the work to be done between them, with consequent lessening of the working strain on each. The results of research work along this line suggest great possibilities, more particularly in so far as the performance of work in mills and factories is concerned. May it not be that if a workman is turning a grey bar of steel in a lathe whose color is grey, as such machines often are, or an operative working in, let us say, a cotton mill, with a white thread against the grey background of a machine, that only the rods of the operative's eyes are active. If, however, the machine were colored, as it well might be, both the rods and cones would be active, with the work being done, divided between them and a consequent lessening of the strain on each of these forces individually.

The author of a paper delivered during the 1913 *Transactions* of the Society made use of an expression which I trust he will pardon my paraphrasing at the very end of the closing sentence of this paper. It seems that every illumination problem that comes to us for solution possesses some aspect, some condition which makes it differ from every other question we have had to consider. It is this which gives each problem its illusive quality,

which makes each problem interesting, and we can truly say that the successful illuminating engineer in the handling of the illumination of architectural and decorative interiors is he who in conjunction with all the curves and knowledge he can command, can short circuit the solution through the fourth dimension of intuition.

GAS LIGHTING IN A CATHEDRAL.*

BY JAMES D. LEE, JR.

Synopsis: This paper is a description of the application of illuminating engineering principles as employed in gas lighting and specifically treats of an installation of semi-indirect gas lighting in a cathedral. The choice of an illuminant for this class of lighting is carefully considered, together with the other essential features entering into the problem. The attempt has been made as far as possible to accomplish the same results in the artificial lighting as are effected under daylight. The intelligent investigation by means of an experiment forms an interesting chapter in the engineering of gas lighting. The results of the complete installation have been investigated and every facility that is offered to the engineer to analyze his work has been employed. This marks a step in the progress of gas lighting.

The Cathedral of SS. Peter and Paul on Logan Square, in Philadelphia, has stood for fifty years as one of the finest examples of classic architecture to be found in this city, which is noted for its beautiful churches.

Recently a new system of gas lighting was installed as part of a general renovation which the church had undergone. This installation of gas lighting is all the more noteworthy in that the same careful considerations which usually govern the choice of an illuminant for church lighting were applied and the gas lighting adopted. The gas units installed were carefully selected to fulfil the esthetic requirements of the case.

The cathedral is lighted in daytime by clerestory in the nave and by skylights in the aisles.

Any effect this method of lighting would have on the prominence of architectural features due to optical corrections of light and shade were difficult to realize since at different periods during the day the conditions change. The cathedral faces the west. The north aisles and north side of the nave, if viewed from the south side, present during the early forenoon when bright sunshine is streaming through the clerestory a bright surface against a dark background.

* A paper read at the mid-winter convention of the Illuminating Engineering Society, New York, February 10, 11, 1916.

Prominence is naturally given to the face of the pilasters. Whereas reversing one's position to the north aisle, the glare of light through the clerestory openings throws the face of the pilasters on the south side of the nave into strong shade against the bright walls lighted by the skylight above the aisle. Here there is evidence of the reversal of the effect which gave prominence to the north side of the nave.

It was observed, however, that at one period of the day a condition existed where every part of the church appeared well lighted. This condition was noticeable by reason of the facility with which every detail was best seen. The sky out-doors was overcast and no particular direction given the light. The effect was not so strikingly beautiful as at other times when long shadows were thrown down the aisles and the play of light on certain details lent a new interest to the interior. It was in an effort to simulate the best effect and provide comfortable easy seeing conditions that the artificial lighting was planned.

It would seem that the success of this installation marks a step in the progress of gas lighting. The progress that has been made from the time when open flame gas jets did service even for churches and other large public buildings, to that period when it was thought that electric lighting had all but driven gas from this field entirely, is an advance which is indeed very marked. Even the introduction of mantle burners was not sufficient to stop the inroads electricity was making on this class of lighting. Nothing short of an innovation in lighting made possible the success of this gas installation.

The certain advantages inherent in electric lighting were too great a handicap for gas to overcome. Not the least of these advantages is the facility with which electric lamps of various types and sizes may be utilized; but the principal one is the easy means afforded for controlling the light with suitable reflectors. Not that gas lamps were used without reflectors, but efficient reflection from the most carefully designed accessory has been difficult with gas lamps. Nothing like the values attainable with reflectors used on electric lamps could be had with the reflectors used on gas lamps. The closer approach to a point source enabled a more efficient reflection and control of the light possible

with the electric lamps. The gas lamps on the other hand were largely extended surface radiators and the heat of the lamp made the close surrounding of light source impracticable.

The persistency with which gas men held to large light units, occasioning what in times past was considered an extravagant waste of light on side walls and ceiling, resulted in the substitution of competitive illuminants, by which a greater efficiency of utilization of light was accomplished. Every effort was made to deliver all the light possible downward—to be effective over a horizontal plane. The criteria by which an installation was judged to be effective were based on the ratio of the flux of light generated to that received on the plane of reference.

Later developments in illuminating engineering are interesting as showing the trend of ideas concerning the principles of good and effective lighting. Illuminating engineering made its first claim on public attention through its endeavor to efficiently utilize light inefficiently produced. The attention focused so closely on this desire for improved efficiency was productive of the greatest achievement in lamp production, the accomplishment of high efficiency lamps.

The improvement in lamp efficiencies, both gas and electric, had a marked influence on the manner of utilizing light. The necessity for diffusion became at once apparent. While incandescent electric lamps increased in efficiency, this was accompanied with an increase in specific intensity. Gas lamps on the other hand, acquired a greater efficiency, due to an improvement in combustion of the gas. A more efficient combustion, due to a more intimate mixture with air, and less excess air resulted in a reduction of gas consumption while the area of the radiator changed but little, as did the brilliancy or specific intensity.

There is no doubt but that the increase in efficiency of electric incandescent lamps was due largely to the change from temperature or black body radiation, in the old carbon filament lamps, to selective radiation, in the new metal filament lamps. Selective radiation of the highest order is also responsible for the great light output of incandescent gas mantles. The facility with which the quality of light is controlled by simply proportioning the

ceria content of the lighting fluid, with which a mantle is saturated, is an advantage inherent in gas lighting.

The increased temperature at which it is possible to operate the metal filament lamp without unduly shortening its life, and the probable conduction of heat through the gas which replaces the vacuum of the old type lamps, introduces an element which in gas lighting was thought to be a handicap; namely, its heating effect. The reduction in gas consumption accompanying the improvement in gas lamps, lessens the gap which separated these two modes of lighting.

The precautions usually taken to dissipate the heat of gas lamps and deflect it from the nearest points of contact are deemed sufficient to guard against discoloration and deterioration. Radiation, such as accompanies all light which being absorbed, is manifested in the heating effect on an enclosing globe or dish, commands the attention of the lighting engineer whether he uses gas light or electric light.

With the improvement in lamp efficiencies came improvements in reflectors. The two combined to develop an extreme condition detrimental to the eyes and made the so-called efficiency or utilization of light neither desirable nor essential to economic lighting. Other elements, than mere considerations of economy, were introduced and commanded attention.

Illuminating engineering had to deal more particularly with a means of providing diffusion and insuring eye comfort. Considerations of the eye as a delicate organ and the growing appreciation of those principles of good lighting which make possible comfortable vision under the most trying conditions now govern largely the manner of utilizing light.

Under favorable conditions, the high intensities of illumination once found necessary with direct lighting are no longer required with the improved methods of installation. Careful attention to brightness distribution, and an attempt to avoid as far as possible, undue contrasts of brightness, provide ideal conditions for comfortable seeing, even with low intensities of illumination. Semi-indirect lighting in which approximately 70 per cent. of the light is delivered above a horizontal line drawn through the unit, now, is made to accomplish results which, if contrasted with the

former method of direct lighting, are indeed remarkable. In short, this is the innovation in modern methods of utilizing light that bespeaks the success of gas lighting in the cathedral.

Semi-Indirect Lighting with Gas.—Unlike direct lighting where every effort is made to utilize the total quantity of light produced, directing it downward, or within controlled limits over a surface to be illuminated, semi-indirect lighting depends upon the reflected light from the bright surfaces of the ceiling and upper parts of walls to return some small quantity of light upon every object, so that these may be readily seen. The effect is such that in most cases only 25 per cent. of the total light generated is used for the specific purpose for which the illumination is intended. By design 75 per cent. is utilized to provide a background, as it were, for the source. Most of the light, approximately 75 per cent. is delivered upward and only 10 to 15 per cent. is reflected in return. The loss in reflected light is due to the absorption of surfaces which are poor reflectors. Of the 25 per cent. delivered downward, the density of the glass bowl of the fixtures accounts for 20 to 30 per cent. loss in transmission through the glass.

The worth of such a seemingly extravagant waste of light in the semi-indirect system is realized in the easy discernment of every object viewed. Without effort we may distinguish objects and our vision is made more acute. One feels that it is not necessary to shift about so as to receive more light from direct sources, which heretofore have been so conspicuously bright. The eye adjusts itself to the brightness of its surroundings and failing to find one thing brighter than another, focuses the attention on the object to be examined. In semi-indirect lighting there is not the distraction of an excessively bright source, nor is the accommodation of the eye taxed by a constant readjustment to different intensities in the field of view.

With gas as the illuminant, the quantity of light necessary to be produced results from a comparatively low surface brilliancy and large surface area in the unit. This provides the pleasing quality of light so essential to the success of semi-indirect lighting. No extraordinary precaution is necessary to be taken to obtain a glass so dense that the source of light cannot be distinguished through it. The glass need not be tinted so as to give a pleasing

color quality. The losses consequent upon such a necessity would be a serious handicap. The color of light from a gas mantle is controlled effectively in the lighting fluid, furthermore, the texture of the glass can be such that the beautiful play of color or fire, resembling the beauty of an opal, lends life and interest to the glass and relieves the dead flat effect of the dense diffusing glasses.

Preliminary Estimates of Quantity of Light.—As a preliminary estimate of the amount of light required for semi-indirect lighting with gas (the efficiency of utilization is the same whatever the illuminant may be) it need not be expected to retain more than 25 per cent. of the total light in most installations, depending upon the color of the walls and ceiling. Expressed in the form of an equation the total light equals the area in square feet multiplied by the illumination desired in foot-candles divided by 0.25.

The mounting height and distance from ceiling, to some extent, influence the uniformity of the illumination and the spacing of the units. It must be borne in mind, however, that the success of a semi-indirect lighting system depends more upon brightness distribution and brightness contrasts than upon any other consideration.

It is desirable to keep the brightness of the dish within certain limits—from 0.25 cp. per sq. in., 121.7 ml., to 1 cp. per sq. in., 486.8 ml., is permissible. Having established a desirable limit of brightness for the dish, the brightness of the surrounding surfaces may be two hundred times less than the brightness of the dish. Contrasts of brightness between the brightest and darkest surfaces exceeding two hundred times the brightness of the surroundings may be permissible, provided the brightness of the dish is of a low order. The extent of the surface is not likely to cause a condition of glare so long as the brightness is of low value.

Preliminary Estimates of Gas Consumption.—The total consumption of gas in cu. ft. per hour is governed by the efficiency of light production of the horizontal type burner used; approximately 315 lumens per cu. ft. and 2.75 cu. ft. per mantle have been assigned to this type burner under favorable conditions of test. An intensity of 1 foot-candle is considered sufficient for

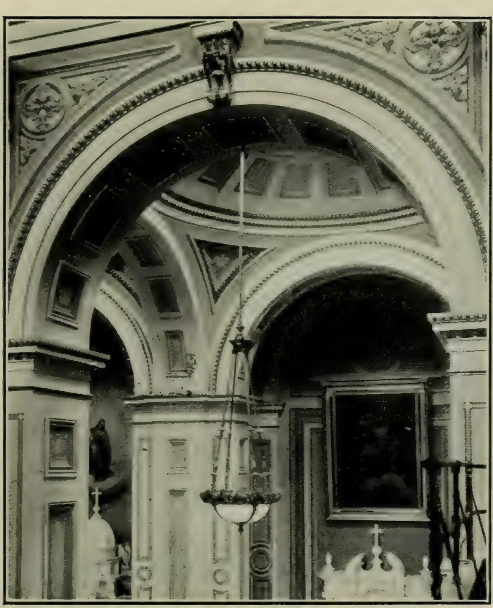


Fig. 1.—Gas fixture designed to conform to the interior decorations.

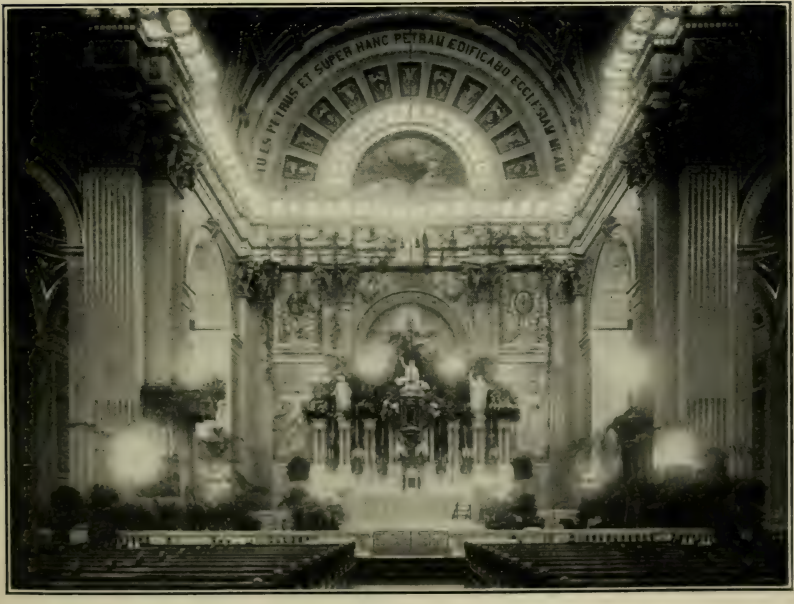


Fig. 2.—View illustrating objectionable glare from outline lighting.

Fig. 3.—Illustrating the diffusion obtained by the improved method of installation.

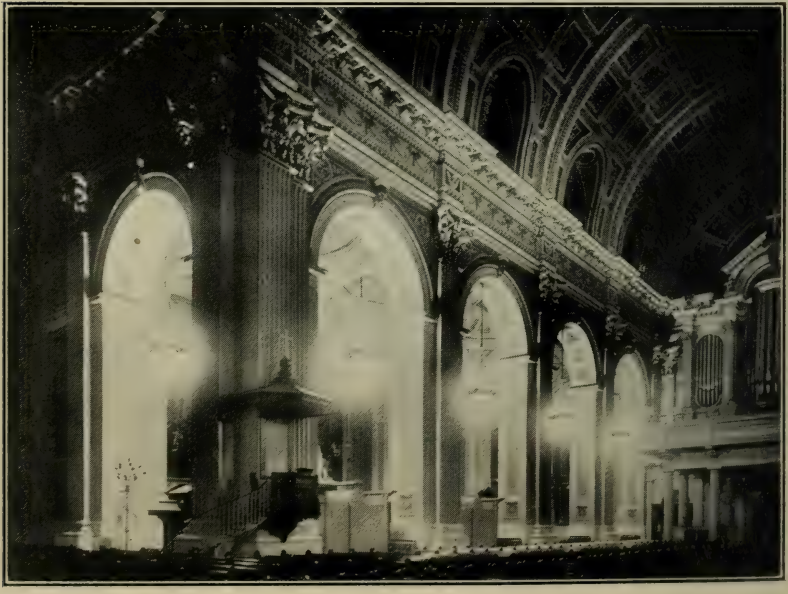


Fig. 4.—Illustrating the locations selected for the light sources back of the congregation.

Fig. 5.—Illustrating the flood lighting effect on the side altars.

Fig. 6.—Illustrating the illumination of the frescoes in the chapels.

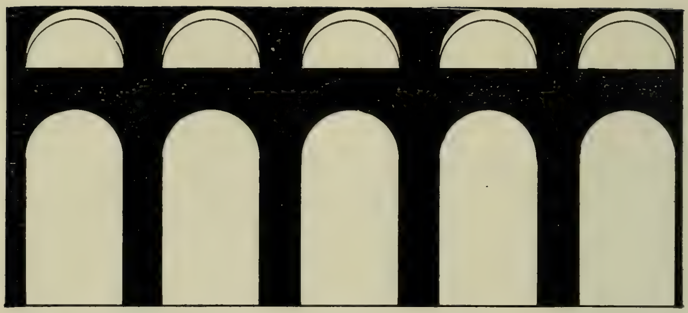


Fig. 7.—Illustrating the reversal of the effect which gave prominence to the architectural details.

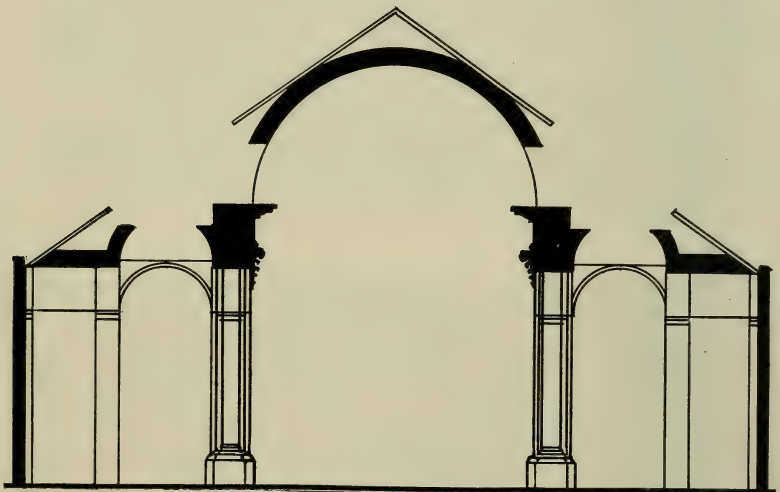


Fig. 8.—Diagram showing the method of daylight illumination.

Fig. 10—Illustrating the prominence given the architectural detail by viewing a bright surface against a dark background.

church lighting. The total consumption of gas in cu. ft. per hour may be estimated from the following formula:

$$\frac{\text{Area} \times \text{foot-candles}}{0.25} = \text{total lumens};$$

that is, area in sq. ft. multiplied by desired intensity in foot-candles divided by the factor for the assumed efficiency of the installation. Only 25 per cent. of the total light could reasonably be assumed to be effective. This value may be found to be high in this instance. Thus:

$$\frac{(130 \text{ ft.} \times 200 \text{ ft.}) \times 1 \text{ foot-candle}}{0.25} = 104{,}000 \text{ lumens.}$$

Dividing the total lumens required by the lumens per cu. ft. equals the total gas consumption. The total gas consumption divided by the consumption per mantle equals the total number of mantles required. Having 12 locations from which to distribute the units, the total number of mantles divided by 12, equals the number of mantles per fixture.

In estimating the total quantity of light required and the total quantity of light produced there are obtained values which determine the number of mantles required, the number of burners (having a certain number of mantles each) to each outlet and fixture, the spacing of the outlets, etc., etc. The total number of cu. ft. of gas per hour required and the lengths of pipe runs, determine the size of pipe required to pass that quantity of gas at a pressure sufficient for satisfactory operation of the burner.

There is no doubt but that with satisfactory service conditions, *viz.*:—constant and uniform pressure, quality of gas, with respect to specific gravity and B. t. u. content, the burner is sure to operate efficiently. Nevertheless, there is no exact method of adjustment, whereby a certain efficiency can be ascribed to any burner unless all known factors are set forth. It is for this reason that a depreciation of 25 per cent. is often allowed on laboratory tests, so as to insure a certainty of results in an installation. This discrepancy is due not to an inexact method of rating gas lamps, but rather to the fact that no satisfactory method of rating has become standardized. A gas lamp tested under conditions exactly similar may vary in efficiency with the specific gravity or the B. t. u. content. Neither the method of

rating a gas lamp according to lumens per cu. ft. nor the lumens per B. t. u. suffice to tell the complete performance of a lamp.

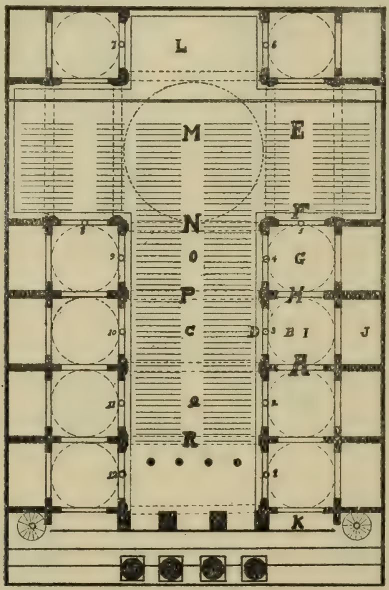


Fig. 9.—Ground plan of cathedral.

Under actual service conditions gas lamps are just as likely to be under-rated as over-rated. The possibility of adjusting gas lamps at regular intervals of cleaning makes their average performance, during the life of the mantle, a high value in the order of excellence.

FACTORS CONSIDERED IN THE PROBLEM.

Improved methods of installation and attractive lighting units, together with careful attention to the dictates of good lighting, were compelling factors in this problem. The elements of economy, *viz.*: convenience, flexibility, and efficiency, did not outweigh the considerations of diffusion, eye-comfort and suitability. The gas units were suitable as the fixtures were designed to conform to the interior decorations of the church. The whole installation fits into, rather than stands out from, the general scheme, the keynote of which is the fitness of things. The mellow tints of the rich frescoes are preserved in the gas light.

The latest development in burner construction (the kinetic type horizontal burner) admitted of readily concealing the burner within the bowl of the semi-indirect fixture, and made possible the most flexible lighting unit commercially available. The number of mantles per burner was only limited by the size of the translucent bowl. The bowl was constructed of bent glass panels rather than of one piece blown glass. This precaution was taken to allow for expansion, and to lessen the danger of breakage.

In a tentative arrangement for the purpose of our experiment which also served as a demonstration of the illumination intensity to be expected, 3 5-light burners were installed in one fixture. These burners are available in 2, 3, 4, 5 and 8 mantles each, or special burners to carry any number of mantles can be made. Each of the burners were provided with a separate cock so that 3 degrees of illumination were available in the light unit.

A careful positioning of the burners within the dish determined the brightness of the bowl. The brightness of the dish was contrasted with the brightness of the surrounding background. By lowering or raising the fixture and noting the desirable limits of brightness contrast the final position of the fixture was decided.

The cathedral structure is in the form of a latin cross and the outlets were provided in the two arches on either side of the main altar (there are eleven altars in all) the two arches in the rear of the transept and one in each of the arches on either side of the nave. The north and south aisles of the cathedral are occupied by chapels on either side of the nave. The light reflected from the low domes above these chapels serves to light the altars located in these places.

The pews are arranged lengthwise of the transept and across the nave. The congregation facing towards the front of the church have a clear and unobstructed view of the main altar. The light units supported in the arches on either side are partly concealed by the heavy pilasters supporting the ceiling of the nave.

The great area enclosed in the transept presented a difficulty in providing a sufficient amount of light in the two fixtures in-

stalled in the arches in the rear. By increasing the amount of light in the two fixtures forward in the nave an illumination of sufficient intensity was provided.

The completed installation comprises twelve fixtures (six with fifteen mantles and six with twelve mantles per fixture) conforming in design to the architectural period of which this church structure is a pure example. The heavy brass acanthus leaves, composing the rims of the bowls, together with the fluted ribs supporting the panels of glass, ending in the familiar egg and dart finished canopy, supply, the motif in design. The fixtures are massive in structure, but hang gracefully pendent within the supporting arch, the great height of which loses in perspective any suggestions of clumsiness. The fixtures weigh close to 200 pounds each and are securely fastened in the masonry of the arch.

The piping extends through the loft above the low chapels on each side of the nave and drops down to the solid structure of the arch and is supported securely with expansion bolts. To reach these points it was necessary to chase the inner-faces of the arch and destroy much of the finished ornament. This latter was replaced and finished so as to leave no trace of the pipe.

Lighting Hours.—The lighting is so arranged as to be serviceable for all occasions requiring artificial illumination. At the early morning services which are conducted every day of the year, the two fixtures on either side of the altar and the two back of the transept and the two forward in the nave are lighted. These are sufficient to provide illumination for the small congregations assembled for these early morning services which last about three hours. The church is open every day during the week, in the evening for about two hours. Two fixtures have proved sufficient to light the entire church to an intensity sufficient to enable any one to find his way about without effort. On Sunday all fixtures are lighted at 4.30 A. M. and remain lighted until after 12.30 noon on dark days. Evening services on Sundays and other days throughout the year require the entire installation to be used three hours.

RESULTS.

Illumination and brightness measurements have been made

with a carefully calibrated Macbeth illuminometer and accurate information is available for future guidance. Such information as may be acquired from a study of existing installations is of special value and may be used to insure successful results in our later undertakings.

The illumination and brightness readings were taken by Mr. R. F. Pierce of the Welsbach Company corresponding to the locations designated on the plan as follows:

A. 0.00185 cp. per sq. in.—arches of chapels, 0.9 ml.
B. 0.00185 cp. per sq. in.—domes of chapels, 0.9 ml.
C. 0.000676 cp. per sq. in,—ceiling of nave, 0.32 ml.
D. 0.301016 cp. per sq. in.—brightness of dish, 146.5 ml.
E. 0.2565 foot-candle—transept first front pew.
0.3382 foot-candle--transept midway to fixture directly beneath.
F. 1.74 foot-candles directly beneath unit No. 5 (15 mantles).
G. 1.37 foot-candles.
H. 1.04 foot-candles.
I. 1.04 foot-candles.
J. 0.00088550 cp.—brightness of altar.
K. 0.000095 cp.—brightness of darkly painted picture.
L. 0.0002 cp.—brightness of main altar, 0.97 ml.
M. (1) 0.2223 foot-candle—transept middle aisle front pew.
(2) 0.2603 foot-candle—transept middle aisle midway.
O. 0.38 foot-candle—transept middle aisle first pilaster.
N. 0.58 foot-candle—nave middle aisle between units No. 4 and No. 9.
P. 0.58 foot-candle—nave middle aisle between units No. 3 and No. 10.
Q. 0.58 foot-candle—nave middle aisle between units No. 2 and No. 11.
R. 0.475 foot-candle—nave middle aisle under organ loft.

CONCLUSION.

In conclusion it might be stated—it is doubtful if a more thoughtful consideration of the requirements of good lighting practise could be given any other illuminant. It will be recognized that the foregoing features as outlined above are the only factors with which any carefully planned lighting installation has to deal. The preference which is naturally given a form of lighting that combines all the requisites of satisfactory and efficient operation, justifies the claims for excellence in this installation.

TRANSACTIONS

OF THE

Illuminating Engineering Society

NO. 7, 1916

PART II

Miscellaneous Notes

Special Meeting of the Council, Sept. 20, 1916.

A special meeting of the Council of the Society was presided over by Dr. Charles P. Steinmetz, in the Green Room of the Bellevue-Stratford Hotel, Philadelphia, Pa., Sept. 20, 1916. In addition to President Steinmetz, the following members of the Council were present: Chas. O. Bond, A. S. McAllister, Geo. A. Hoadley, J. L. Minick, J. D. Israel, H. Calvert, S. G. Hibben, Preston S. Millar. Upon invitation, Mr. Wm. J. Serrill and Mr. G. H. Stickney attended the meeting. The meeting was called to order at 5.30 P. M.

Mr. Calvert, Chairman of the Committee on Finance, submitted the report for that committee. Voucher No. 2586 to 2633, inclusive, were approved for payment.

In order to cover the outstanding bills incurred through the increased activities of the Society, Mr. Calvert moved that the treasurer of the Society be instructed to sell the remaining bond. This motion was carried.

Upon suggestion of Mr. Preston S. Millar, Chairman of the Administrative Committee on Lectures, it was moved and carried that the Administrative Committee on Lectures be asked to make a temporary loan to the Society.

Upon recommendation of Dr. A. S. McAllister, Chairman of the Board of Examiners, two companies were elected to sustaining membership and six applicants elected to associate membership. Action on applicants for admission to the grade of member and those applying for transfer to this grade was deferred to the next meeting of the Council.

Dr. A. S. McAllister, Chairman of the special By-Law and Constitution Committee, and also of the special Transactions Expense Committee, made verbal reports for both committees. Dr. McAllister was requested to present both of these reports to each member of the new Council for their consideration preceding the next Council meeting, at which time formal action would be taken.

The meeting adjourned at 6.00 P. M.

New Sustaining Members.

The following two companies were elected sustaining members of the Society at a meeting of the Council, held September 20, 1916:

ADIRONDACK ELECTRIC POWER CORPORATION
7½ Ridge St., Glens Falls N. Y.

NEW YORK AND QUEENS ELECTRIC LIGHT & POWER CO.
444 Jackson Ave., Long Island City, N. Y.

New Members and Transfers to Grade of Member.

Action on the applications for full membership and for transfers from associate to grade of member were referred to the next meeting of the Council.

New Associate Members.

The following six applicants were elected associate members at a meeting of the Council, held September 20, 1916:

CALDWELL, O. H.
Assistant Managing Editor, *Electrical World,* 239 W. 39th St., New York, N. Y.

CHRISTESEN, CHARLES JOHN
Electrical Engineer, New York Edison Co., 130 E. 15th St., New York, N. Y.

EGELER, C. E.
Engineering Dept., National Lamp Works, Nela Park, Cleveland, Ohio.

HAMM, WM. S.
Expert, The Adams Westlake Co., 319 W. Ontario St., Chicago, Ill.

HENRY, J. R.
Salesman, National X-Ray Reflector Co., Indianapolis, Ind.

SHACKELFORD, BENJ. E.
Physicist, Westinghouse Lamp Co., Bloomfield, N. J.

President William J. Serrill. 1916-1917.

William J. Serrill, on October 1, 1916, assumed the presidency of the Illuminating Engineering Society, succeeding Dr. Charles P. Steinmetz, whose successful administration terminated on that date.

Mr. Serrill was born November 10, 1862, at Darby, Pa., a suburb of Philadelphia. After graduating from the department of mechanical engineering of the University of Pennsylvania with the class of '83, he was employed for two years with the Southwark Foundry & Machine Company in Philadelphia. In June, 1885, he entered the employ of the United Gas Improvement Company of Philadelphia, serving in various capacities in the engineering department. Mr. Serrill is now Engineer of Appliances in this company. In 1897 the United Gas Improvement Company leased the Philadelphia Gas Works and Mr. Serrill was appointed and still holds the position of Engineer of Distribution of this company. In 1909 he became a member of the Illuminating Engineering Society, serving in 1910-1911 as chairman of the Philadelphia Section and later in 1912-1913 and also in 1913-1914 acting as Vice-President of the Council, representing the Philadelphia Section for that body. Mr. Serrill was treasurer of the Society for the fiscal year 1911-1912. A recent photograph of President Serrill appears in the front of this number.

New Section Officers, 1916-1917.

Your attention is called to the newly elected Council and Section Officers for the fiscal year commencing October 1, 1916, which appear on the inside front cover page and on the pages following this page entitled "Sections." The names of the chairmen and committee men of the various standing and temporary committees will be inserted in the corresponding sections as soon as the appointments are made and accepted.

Passing of the Tenth Annual Convention.

The days of September 18 to 20, 1916, marked the passing of the most successful convention in the annals of the Illuminating Engineering Society. The weather was especially favorable to the outdoor automobile trips and the cool, clear atmosphere afforded most pleasant conditions in the convention hall at the Bellevue-Stratford Hotel.

Registration was brisk during the opening day and the close of the convention brought to light the fact that nearly 450 delegates and guests had entered their names. The attendance at the various sessions and social features of the program was especially consistent in point of numbers. It seemed that nearly every delegate was there for the "whole show."

From the standpoint of administrative representation this convention again exceeded others—sixteen of the nineteen members of the Council were in attend-

ance. Enthusiastic delegations came from each of the five section centers, while the membership not within section boundaries was well represented.

The papers presented at the various technical, commercial and general sessions were well received and some interesting discussions were suggested by them. Outlines of these papers were forwarded to the membership preceding the convention and all of the papers will be published in forthcoming issues of the TRANSACTIONS.

The automobile trips to the Aronomink Golf Club on Monday and to Valley Forge on Tuesday were enthusiastically enjoyed by the ladies. Approximately sixty guests of the Society enjoyed these outings.

On Monday evening in the Rose Garden of the Bellevue-Stratford, some three hundred delegates attended the reception to Dr. Charles P. Steinmetz, the retiring president of the Society. The reception was followed by a piano recital by Madame Mary Hallock playing classics, some of which were accompanied by color-music flooding the platform first with soft nuances of color blending with the delicate low tones and then with brilliant flashes of deep hues harmonizing with the overtones. Following the recital a dance was enjoyed.

Tuesday evening ushered in the tenth annual banquet of the Society. Approximately two hundred delegates and guests enjoyed the service in the Rose Room roof garden of the Bellevue-Stratford Hotel. Edward J. Cattell, Statistician of the City of Philadelphia, acted as toastmaster, introducing in a most genial manner, Messrs. Joseph B. McCall, William H. Gartley and William J. Serrill. Between courses and after the banquet the delegates again danced to the strains of the waltz, one-step and fox-trot.

The closing day of the convention was given over to a session of general papers in the forenoon and the afternoon was spent in viewing the exhibits of the lecture course in the Engineering Building at the University of Pennsylvania. The evening of Wednesday, September 20th, introduced to the convention attendants, the opening address of the lecture course, delivered in the Museum of the University of Pennsylvania.

The Illuminating Engineering Lecture Course.

The Illuminating Engineering lecture course at the University of Pennsylvania under the joint auspices of the Illuminating Engineering Society and the University has been brought to a successful conclusion. Approximately 200 tickets were sold to the lectures for the entire course, and approximately 60 tickets were sold for particular lectures. The audiences to the restricted lectures ranged from 85 to 185 in number. Seven or eight hundred persons attended the lectures which were thrown open to the public at the beginning of the course.

The committee having this matter in charge are now at work on the problem of printing the lectures, and every effort will be expended to make the bound volume of lectures available at an early date. It is expected that this volume will be offered to the membership of the Society at a lesser price than to the general public.

The exhibition in connection with the lecture course was a notable success. It brought together scientific and commercial apparatus of large educational value which was highly appreciated by those who participated in the course.

The inspection tour was not as largely

patronized as had been hoped, but those who did participate found much to repay them for their expenditure.

The helpful courtesy of representatives of the University was an outstanding feature of this lecture course which will be gratefully remembered by all who attended.

TRANSACTIONS
OF THE
Illuminating Engineering Society

VOL. XI — NOVEMBER 20, 1916 — No. 8

REPORT OF THE COMMITTEE ON PROGRESS.*

Men travel far a-field, I find,
  With happiness in sight,
Or else they'll turn them round and round,
  And only search for light,
    Light, more light!

(After the *Norwegian of Per Sivle,* translated by H. G. Chapman.)

INTRODUCTION.

Of the two great events mentioned in last year's report, one, the Panama-Pacific Exposition, has passed into history, the other, the great war, is still a factor in the world's activity. The marvelous lighting effects of the former have provided an example in illuminating engineering the effect of which is immediately apparent in the increased use of flood lighting. The prestige of the illuminating engineer has been enormously enhanced and doubtless, the employment of illuminating engineers in many instances might be traced directly to the results accomplished at the Exposition. The war is still a sinister shadow darkening abroad a year which has been replete with progress at home.

A section of this report has been devoted to flood lighting. The use of high-powered units to illuminate large areas, the exteriors of buildings, monuments, etc., has grown to an enormous extent and is one of the most striking developments of the year. The varied forms in which this idea is being applied are surprising. Thus, it is being used in flag lighting as a means of showing patriotic sentiment; in the lighting of court houses and

* A report presented at the tenth annual convention of the Illuminating Engineering Society, Philadelphia, Pa., Sept. 18-20, 1916.

(Condensed somewhat for the TRANSACTIONS by the Committee on Editing and Publication at the suggestion of the Committee on Papers and with the approval of the Executive Committee.)

public buildings as a medium for maintaining civic pride; in the lighting of playgrounds and amusement grounds to enable them to be used at night; in building operations to facilitate continuous construction; and in numerous cases of emergency lighting.

The publication of the report of the Committee on Lighting Legislation has aroused considerable interest and stimulated action on this most important branch of illuminating engineering. The same thing is true of the report of the Departmental Committee on Lighting in Factories and Workshops, in England.

The extent to which the possibilities of illuminating engineering are reaching all classes of people is well illustrated[1] by an article in a church periodical, written by a clergyman experienced in preaching to the deaf. He calls attention to the need of a special type of pulpit illumination which without annoyance from glare, will adequately illuminate the speaker so that lip reading may be done by the congregation.

As heretofore the members of the Committee wish to express their thanks to those who have given information and to the technical and scientific press whose columns have been freely used and referred to.

Respectfully submitted,

F. E. Cady, *Chairman,*
W. B. Lancaster,
T. J. Litle, Jr.,
F. N. Morton,
T. W. Rolph.

[1] *Elec. Rev. and W. E.*, June 3, 1916, p. 1007.

SUBJECTS.

GAS AND OIL LAMPS AND APPURTENANCES.

This year is the one-hundredth anniversary of the successful introduction of gas for illuminating purposes in this country. The event was celebrated[2] June 16 and 17 in Baltimore, the location of the first installation.

A National Gas Lighting Week was observed from Sept. 27 to Oct. 2. The object was to make the public conversant with the flexibility and range in sizes of the units now available and with other information regarding gas and its applications. Special efforts were made in New York, Philadelphia, St. Louis and other large cities.

Burners.—The rapid introduction of the upright lamp fitted with inverted mantles has been the most marked development during the past year. For residences this takes the form of a semi-indirect unit fitted with three small artificial fiber mantles in limp rag form. Outdoor lamps of high efficiency have been developed along similar lines. In these the Bunsens and entire

[2] *Am. Gas Lt. Jour.*, June 12, 1916, pp. 369, 371, 403.

burner head or manifold portions are within the globe. For porches a new lamp is announced which is very small and compact and of low cost.

The Berlin gas companies announced[3] last September that the constitution of the coal gas supplied would be so altered after the middle of the month that it would be impossible to use fishtail burners and all house owners were warned to replace them with incandescent mantles.

The results of an extended investigation[4] on the inner cone of a Bunsen flame have been published and the characteristic conical form explained by the distribution of velocity of the particles in the burner tube. Incomplete consumption at the surface of the inner cone may be decreased by increasing the pressure. For pressures between zero and two atmospheres there is a maximum temperature rise for a carbon-oxygen-air flame. The highest attainable temperature for this gas mixture is 2,000°.

Ignition.—Engineers have long been seeking a more satisfactory method of ignition than those at present in use and the most striking innovation of the year has been the development of a gas glower for the purpose. This consists of a bundle, cylindrical in form, about one-quarter of an inch in diameter and of about the same length, made up of several thousand filaments made from rare earth material, similar to that used in incandescent mantles. Gas is delivered to the center of the mass and combustion takes place throughout but with greatest intensity at the top. The device consumes approximately one twenty-fifth of a cu. ft. per hour or 350 cu. ft. per year, which is about one-half that consumed by the ordinary pilot flame of a residential burner.

Among the characteristics of this glower might be mentioned the amount of light given off which is sufficient for the reading of newspaper print at 10 in. distance. But the most distinctive property is the ability to withstand drafts. One side may be cooled below the point of incandescence while the other side will still glow brightly, a rapid rekindling occurring when the draft is removed.

A new pilot[5] for gas lamps has a space allowed in the main body of the cylinder for a storage supply of gas that will prevent

[3] *Jour. of Gas Ltg.*, Sept. 14, 1915, p. 582.
[4] *Jour. of Gasb.*, Jan. 22, 1916, p. 49.
[5] *Gas Age.*, Feb. 1, 1916, p. 168.

it from sniffing out when the lamp is being turned on or off. It is claimed that it will not clog up from impurities, nor be stopped up by pipe rust, thus overcoming some of the objections to needle-point pilots.

Distance Control.—An electro-magnetic cock has been worked out for the distance control of gas lamps. It is condensed in form of simple construction and may be operated by the current from a single dry battery. It requires no lubricant and will operate satisfactorily through a considerable range of temperature.

Mantles.—For new installations the upright mantle has been almost completely dropped in favor of the inverted type. The great increase in the use of natural gas and the gradual adoption of the calorific standard have caused a rapid extension of the use of incandescent mantles to replace the inefficient flat-flame burner.

A German inventor proposes[6] to use plush of a suitable texture as the fabric for a gas mantle instead of ramie or cotton. It is claimed that plush can be impregnated and burnt off as in the ordinary mantle and that its capacity for emitting light is considerably greater without prejudice to its desirability and cost of production. The process of combustion in a plush mantle would be as follows: The gas mixture issuing from the close meshes of the basic texture as through a sieve, ignites at the surface and burns in the channels which run in parallel directions between the threads. The latter glow at their ends with a strong light which decreases toward the interior. The basic fabric prevents backlighting.

The shutting off of the gas supply in order to extinguish lights in case of an air raid has renewed interest[7] abroad in automatic shut-off valves which will prevent the danger from open burners when the gas is turned on again.

In the manufacture of gas in Australia the use of wood mixed with coal has proved[8] quite satisfactory in many of the small gas works. Boxwood and red gum have been found best for this purpose, being mixed with the coal to the extent of 25 per cent.

[6] *Am. Gas Lt. Jour.*, May 29, 1916, p. 349.
[7] *Jour. of Gas Ltg.*, Apr. 25, 1916, p. 177.
[8] *Jour. of Gas Ltg.*, Mar. 7, 1916, p. 524.

As the result of an experiment[9] in which the gas was passed through a tube immersed in solid carbonic acid and ether at –79° C., thus condensing the benzene constituents, it is claimed that the latter are the chief source of luminosity in coal gas. All of the ethylene passed forward with the gas but despite the fact that the volume of ethylene is from three to five times that of the benzene vapor, the former does not apparently contribute much to the light-giving power. In the case of a particular gas, 78 per cent. of the luminous power was lost by the above treatment.

An ordinary kerosene lamp can be converted into an acetylene gas lamp by the use of a so-called carbide candle developed in Germany,[10] where the war has caused a scarcity of oil[11] considerably affecting this ordinarily cheap illuminant. The candle is made in two sizes to fit a 10-in. or a 14-in. burner and is applied by simply removing the kerosene wick-burner and screwing in a movable socket. The stringency of both oil and carbon has led to the formation of a working company[12] in Berlin, under the supervision of the Imperial and Federal State authorities, to supply Germany with lamps for spirit incandescent lighting and particularly for the sale of spirit burners for lighting on a small scale. The burner together with the wick is called a "kriegslicht," and can be screwed on to any existing petroleum lamp. It is essential that mantles and glass chimneys of good quality be used. The new spirit lamps yield 50 hefner candles as compared with 18 from the No. 14 petroleum burner; the consumption of spirit amounts to 0.146 pint or one-twelfth of a liter per hour. For exposed places subject to shocks or strong winds, these lamps are not recommended.

Calorific Standard.—The Public Service Commission for the First District of the State of New York has decided[13] to substitute a calorific standard instead of and corresponding to the present 22 candlepower luminous standard in gas testing. It is proposed to have a number of testing stations where calorimeters will be installed for the measurement of the heating value of the

[9] *Jour. of Gas Ltg.*, Mar. 7, 1916, p. 524.
[10] *Sci. Am.*, Apr. 1, 1916, p. 359.
[11] *Elec. World*, Feb. 26, 1916, p. 470.
[12] *Jour. of Gas Ltg.*, Oct. 5, 1915, p. 17.
[13] *Sci. Amer.*, Mar. 18, 1916, p. 296.

gas. A bill has been recommended[14] to the Massachusetts state legislature providing for a standard of 550 B. t. u. for the state. In Chicago a decided effort has been made[15] to have a calorific standard adopted and a considerable amount of publicity has been used to educate the public to the value of this standard.

In the Dominion of Canada an Order in Council has been issued[16] which decrees that 520 B. t. u. shall be adopted as the calorific standard. It is claimed that this makes Canada the first country to universally institute this standard. Legislation has been started in England[17] to enable any gas company to expeditiously and practically without expense, make the change from a luminous to a calorific standard. The direct object of this legislation is to promote the extraction of benzol and toluol from town gas. In Switzerland[18] the Swiss Association of Gas and Water Engineers have recommended that in the case of all Swiss gas works located at an altitude less than 2,625 ft. (800 m.) the calorific power of the gas should be 483 B. t. u. per cu. ft. at 60° F., and 30 in. saturated. The net calorific power is referred to.

In America the tendency in fixing the value for the calorific standard has been toward values much higher than those adopted abroad. In order to ascertain the most useful value, the Bureau of Standards has written[19] to the English technical press inviting a discussion from English engineers on the subject.

ELECTRIC INCANDESCENT LAMPS.

During the past year the old carbon lamp has almost dropped out of sight[20] and the Gem lamp is rapidly losing its former importance. The sale of tungsten lamps has reached 79 per cent. of the total number of lamps sold. The introduction of the 50-watt 105-125-volt vacuum tungsten lamp will undoubtedly increase this percentage during the coming year. A 75-watt size for the same voltage range which can be burned in any position

[14] *Jour. of Gas Ltg.*, Mar. 7, 1916, p. 534.
[15] *Jour. of Gas Ltg.*, Jan. 25, 1916, p. 198.
Gas Age, Feb., 1915, p. 232.
[16] *Jour. of Gas Ltg.*, Sept. 7, 1915, p. 498.
[17] *Jour. of Gas Ltg.*, June 6, 1916, p. 493.
[18] *Jour. of Gas Ltg.*, Apr. 11, 1916, p. 86.
[19] *Jour. of Gas Ltg.*, Feb. 15, 1916, p. 349.
[20] Report of Lamp Committee of N. E. L. A., May, 1916.

has been added[21] to the list of gas-filled lamps and a range from 200 to 1,000 watts has been provided in the gas-filled lamps for the 220- to 250-volt circuits. The tungsten lamp in a blue bulb approximating daylight is now available in sizes ranging from 75 to 600 watts. The use of gas-filled lamps has also been extended to automobile headlights which, in conjunction with low voltage lighting circuits, are available in sizes ranging from 12 to 100 candlepower.

Miniature.—For automobiles thirteen different types of lamps are now on the market including tubular, mushroom and dome lights, steering, pilot, head, tail, side and dash lights. Miniature lamps for various kinds of hand lanterns and run from portable batteries, have been developed and have come into extensive use. These should be distinguished from the well known flash-light type and are available for use with all sizes of dry batteries, in current range from 0.5 to 1.25 amperes. The approval by the government of electric lamp outfits for miner's use has created a demand which has been met by the development of a line of miniature lamps for this special purpose. The use of miniature lamps for special decorative purposes is also growing. Abroad[22] tungsten lamps for alternating current circuits in connection with house transformers are now listed in units as small as 5 candlepower.

Developments during the year have been largely in refinements in manufacture. Special attention has been paid to the development of concentrated filament lamps suitable for projection purposes in connection with flood-lighting equipments, stereopticons, and headlights. The high candlepower gas-filled tungsten lamps in suitable reflecting devices are rapidly coming into favor for stage-lighting equipment. Work is being done on high wattage tungsten lamps for use in moving picture machines to replace arc lamps. Reflector lenses and other accessories have been designed[23] and while nothing has been standardized, practical equipments have been produced which are equivalent if not superior in illuminating power to the ordinary arc projection in the average moving picture house.

[21] *N. E. L. A. Bul.*, May, 1916, p. 386.
[22] *Elec. Times*, Mar. 16, 1916, p. 203.
[23] *Elec. Age*, June, 1916, p. 37.

To provide[24] the proper light source for the new railway semaphore arrangement mentioned in last year's report,[25] special 12-volt, 4-candlepower tungsten lamps have been designed with the filament wound into a single helix ¼ in. long by ⅛ in. in diameter. In order to be certain that the filament is located exactly at the focus of the lens used, a special sleeve was developed, to be soldered over the lamp base after adjustment. The bases are accurately placed on the lamps so as to bring the long axis of the filament parallel to the plane of the rear face of the lens.

The enormous increase in the output of factories manufacturing munitions of war has created here and abroad[26] a demand for special types of lamps for inspection purposes.

Manufacturing.—A method, proposed[27] and patented, for preventing the deposit of volatilized tungsten in the bulb of the gas-filled lamp, uses an electrically charged grid placed above the filament. Another method claims[28] that the use of a mixture of argon and nitrogen or other neutral gas causes less blackening than in the case of lamps filled with pure argon.

Patents have been granted[29] covering the satisfactory use of alloys of zirconium and iron in the making of tough, malleable and ductile lamp filaments, by simultaneous reduction of the oxides. The zirconium percentage varies between 40 and 90. The iron may be replaced by other metals of the iron group. It is claimed that in addition to the qualities previously mentioned, the alloys resist chemical action and are little liable to oxidation. A patent has also been granted a Swiss inventor covering the preparation of tungsten for lamp filaments. By means of a resistance furnace the tungsten is fused to a perfectly liquid condition and then rapidly cooled by an air blast. It is claimed that this process makes the tungsten exceedingly malleable and ductile. Equations have been worked out and published[30] with data, from which, it is claimed, tungsten lamps may be designed, and specifications have been given for a proposed primary

[24] *Gen. Elec. Rev.*, Jan., 1916, p. 69.
[25] Progress Report, TRANS. I. E. S., Oct., 1915, p. 529.
[26] *Elec. Eng.* (London), May 11, 1916, p. 173.
[27] *Engineering*, Sept. 3, 1915, p. 253.
[28] *Elec. Eng.* (London), Sept. 2, 1915, p. 366.
[29] *Sci. Amer.*, May 6, 1916, p. 465.
See also *Met. and Chem. Eng.*, Dec. 1, 1915, p. 924.
[30] *Zeit. f. Bel.*, Feb., 1916, p. 15.

standard lamp made up with a tungsten filament whose properties are predicted and in view of present refinements in manufacture it is expected such a standard could be made accurately reproducible.

An opal dip to cut down the intrinsic brilliancy of the 50- and 60-watt sizes of tungsten lamps is coming into use[31] and indicates an appreciation of the principles of glare-elimination advocated by this society.

Standardization.—The American Society of Mechanical Engineers has recommended[32] that the dimensions of the threads of the screw shells in electric sockets and lamp bases be standardized. Twenty-seven out of thirty-eight of the largest manufacturers have approved this recommendation.

The efforts of a number of years to standardize incandescent lamp voltages in order to bring about economies in manufacture, distribution and utilization have finally resulted[33] in a co-operative action. The Ohio Electric Light Association having made a careful investigation through a committee, has recommended to its member companies the standardization of their circuits for either 110, 115 or 120 volts. A committee of the National Electric Light Association has been appointed to consider the question.

Rating.—The question of rating lamps on a mean spherical candlepower basis which has been agitated in this country ever since the Bureau of Standards began to press the idea in 1904, has apparently been settled, as the gas-filled tungsten lamps have been so rated since last September[34] and the efficiencies of all vacuum tungsten lamps are now so specified. The introduction of the former lamps might be said to have forced the issue, since their mean horizontal candlepower is affected by rotation, blackening of the bulb and change in shape of the filament. It has been recommended by this society, the National Electric Light Association Lamp Committee and the American Institute of Electrical Engineers that the rating be made in terms of lumens, since the latter has the additional advantage of being applicable to the light delivered on a plane to be illuminated as well as to the

[31] *Elec. World*, July 8, 1916, p. 105.

[32] *Elec. World*, Jan. 29, 1916, p. 260.

[33] *Elec. World*, July 22, 1916, p. 200.

[34] Lamp Committee Report, *loc. cit.*

total light emitted. A survey[35] of the railroad engineers has brought out the fact that the great majority are overwhelmingly in favor of the change from the mean horizontal to the mean spherical nominal rating, and to the lumen for actual rating.

New specifications for the purchase by the Government of incandescent lamps, have been issued as Circular No. 13, dated Oct. 23, 1915. The principle points of difference are that all tungsten vacuum lamps of sizes larger than 100 watts are eliminated and a 10-watt size has been added. The limits of acceptability in watts and watts per candle for the vacuum tungsten lamps have been narrowed. Upper limiting values of efficiency ratings have been increased. Acceptability limits for carbon and gem lamps have been widened in view of the lessening demand for these lamps.

Applications.—The color of the gas-filled tungsten lamp has been found[36] enough "whiter" than the vacuum lamps, to enable its use in zinc refineries for distinguishing between "black jack" (dark zinc ore) and lead. The higher wattage lamps are used for this purpose.

In general[37] the tendency to increase the intensity of illumination used for many purposes has followed as a result of the recent improvements in the incandescent electric lamp.

Physics.—The characteristics of tungsten filaments as functions of temperature have been studied[38] by several observers. Thus experimental data have been obtained and published on the relation between volts, amperes, and candlepower as functions of the temperature and dimensions of the filament. Work has been done and preliminary reports made on the relation between the true, "brightness" and "color" temperatures.

A study[39] of the inside of glowing helically coiled tungsten filaments indicates that the increased brightness of the interior is due in large part at least, to internal reflections and not to a higher temperature. It was found that the temperature difference between the inside and outside was not more than 4°.

[35] *Railway Elec. Eng.*, June, 1916, p. 371.
[36] *Sci. Amer.*, Feb. 12, 1916, p. 173.
[37] *Elec. Rev.* (London), Nov. 26, 1915, p. 683.
Zeit. f. Bel., Feb., 1916.
[38] *Phys. Rev.*, Mar., 1916, p. 302.
Jour. Franklin Inst., Mar., 1916, p. 418.
[39] *Jour. Franklin Inst.*, Nov., 1915, p. 619.

The "over-shooting" in candlepower in tungsten lamps has been tested[40] by actual photometric measurements. By means of contacts operated by a pendulum, the lamp was switched on and a shutter in the eyepiece of the photometer was opened for a fraction of a second, a known and adjustable period after the contact for the lamp had been made. By making repeated trials the voltage on a calibrated lamp was adjusted to give equality of candlepower for the moment of exposure. The conclusion drawn was that in vacuum tungsten lamps there is a small over-shooting due to the heating-up of the central portions of the filament at a greater rate than the end portions, and that there is a noticeable over-shooting in a gas-filled lamp though not very marked, as only 6 per cent. was observed with a filament 0.0065 in. in diameter.

ARC LAMPS.

In the field of arc lamps the most striking developments have been in the use of materials other than carbon for the electrodes. Among others might be mentioned a patent disclosing[41] a method whereby not only the color but the steadiness is stated to be improved. Titanium oxide instead of the carbide and sodium fluoride instead of calcium fluoride are used. The addition of barium fluoride makes the color whiter and increases the stability. Reference is also made to the introduction of fluxes of cerium fluoride and thorium nitride. Mechanical improvements and the standardization of parts[42] have characterized progress in the luminous arc lamp.

Tungsten Arc.—The arc between tungsten electrodes in an inert gas referred to in last year's report[43] has been perfected[44] and put on the market[45] abroad. The difficulty in starting, has been overcome by the use of three leading-in wires, one of which makes connection to an ionizing circuit which is connected after the arc starts. It is claimed that lamps have been made with a life of 500 hours and further experiments are under way to increase this. The intrinsic brilliancy is given as 10,000 candles per

[40] *Ltg. Jour.*, Nov., 1915, p. 256.
[41] *Elec. World*, July 29, 1916, p. 214.
[42] *Gen. Elec. Rev.*, Jan., 1916, p. 23.
[43] Progress Report, TRANS. I. E. S., Oct., 1915, p. 527.
[44] *Jour. of Inst. of Elec. Eng.*, Dec. 1, 1916, p. 15.
[45] *Elec. Eng.* (London), Dec. 23, 1915, p. 511.

square inch when operating at 0.5 watt per candle. The color of the lamp can be made to vary from a bright yellow to a very intense white, the brilliancy limits under these conditions being from 400 to 30,000 candles per square inch. An entirely different[46] type of arc, although using tungsten electrodes, is suggested in the results of the experimental research described before this Society last November. The principle involved consists in providing the material for the arc, not from the electrodes but from a surrounding gas or vapor. The experimental lamp used had an arc chamber at the center of which the arc was drawn between two tungsten electrodes, 0.3 in. in diameter. Among the vapors experimented with were the tetrachlorides of antimony, carbon and titanium, stannic chloride, titanium bromochloride, etc.

A portable arc-lamp lighting unit[47] for use in motion picture photography carries two sets of carbons with automatic feed and equipped to run on either alternating or direct current.

Vapor Lamps.—The use of cadmium in vapor lamps is not new[48] but in the past such lamps have not been very satisfactory, either from the standpoint of operation or life. A new type has been developed which is constructed of quartz, runs at a high temperature on an ordinary direct current lighting circuit, and has a life claimed to be over 100 hours. The main features of this new type consist in the means provided for preventing the vapor from sticking to the quartz surface; the removal of the oxide and dissolved gases from the cadmium; and the seals for the leading-in wires. The adherence to the quartz surface is prevented by the introduction of finely powdered zirconia. The lamp is made in the form of an inverted U, has a terminal voltage of about 30 and takes a current around 5 amperes. A new lamp in which the vapor from zinc chloride or zinc bromide is used[49] at atmospheric pressure has been patented abroad and described by Professor Nernst. It is claimed that the color of the light is white and the efficiency similar to that of the mercury vapor lamp. As in the case of the latter, the inclusion of air or some other foreign gases is prejudicial. However, an atmos-

[46] *Elec. World*, Nov. 13, 1915, p. 1099.
[47] *Elec. World*, July 8, 1916, p. 96.
[48] *Elec. Rev.* (London), Mar. 3, 1916, p. 250.
[49] *Sci. Amer.*, Apr. 8, 1916, p. 377.

phere of aluminum chloride or titanium chloride makes the arc more stable and an atmosphere of nitrogen is harmless.

A new method[50] of automatically feeding the gas to the Moore carbon dioxide tube lamp has been described. Inside the tube and directly behind each electrode is placed a small glass bulb containing calcium carbide with heating wires embedded in it, by which the right quantity of gas is automatically generated. Spectrophotometric data has also been obtained on this lamp.

Through a redesign and improved construction of auxiliaries[51] the power factor of alternating current mercury vapor lamps has been increased from its former value in the neighborhood of 50 per cent. to about 87 per cent. These new lamps have been found to operate satisfactorily on 25-cycle circuits.

Electrodes.—Experiments have been made[52] to determine the rate of consumption of carbons in direct current arc lamps as a function of the current and of the arc length. It was found that the loss per coulomb for a given current density increases with increasing arc length until a nearly constant value is reached at about 8 mm. For long arcs the loss per coulomb decreases with increasing current; for very short arcs (order of 0.1 mm.) at all current strengths from 2 to 100 amperes, the loss per coulomb from the cathode is constant and about 3.2×10^{-5} gm., remarkably near the electro-chemical equivalent of tetravalent carbon.

Rating.—The agitation[53] regarding the mean spherical candlepower rating of glow lamps has raised the question of arc lamp rating and in Germany it has been proposed that arc lamps also be rated for mean spherical candlepower. It has been suggested that this would be a retrograde step since what is desired in the case of these lamps is to know what light is emitted downward and what light in addition is emitted above and is available for redirection by reflectors.

LAMPS FOR PROJECTION PURPOSES.

Hand Lamps.—A novelty in hand or pocket lamps has been brought out[54] in which the power is provided by the muscular

[50] TRANS. I. E. S., Mar., 1916, p. 194.
[51] *Elec. Rev. and W. E.*, Apr. 29, 1916, p. 776.
[52] *Proc. of Royal Soc.*, Dec. 1, 1915, p. 122; Feb. 1, 1916, p. 247.
[53] *Elek. Zeit.*, Nov. 25, 1916, p. 620.
[54] *Elek. Zeit.*, Feb. 24, 1916, p. 108.

activity of the user. The thumb of the hand which holds the lamp moves a lever over a circular path and winds up a spring whose elasticity is made to actuate a small dynamo having permanent magnets for a field source. Enough power is preserved in the spring to keep the lamp burning for a minute without further winding. The lamp used is in form and luminous power similar to the ordinary hand variety actuated by a dry battery. A new portable lamp[55] employs two tungsten lamps backed by a mirror thus greatly increasing the amount of light available without increasing the size of the equipment. Among the novelties in portable lamps[56] may be mentioned one carried in the end of the handle of an umbrella. The handle is detachable and also contains the battery which operates the lamp. By combining a surface gauge[57] with a small flashlight and battery, an indicator has been devised for machinists which not only announces where surface irregularities are found but throws a beam of light which shows just where they occur.

Search-lanterns.—It might at first sight appear to the layman that providing an extra source of illumination at a fire would be like "carrying coals to New Castle," but there have been many cases where additional light has been desirable to permit the removal of valuable material, to penetrate smoke, etc. In such cases, the gas or electric supply is not ordinarily available and a search-lantern truck provided with a special type of battery has been developed[58] to meet this specific need. It consists of a water-proof 20-in. projector on a trunion mounting and fitted with a 35-volt 750-watt focusing type gas-filled tungsten lamp. A hand wheel focusing device enables the beam of light to be quickly and easily spread out or concentrated.

Automobile Lamps.—Efforts are still being made[59] to solve the problem of reducing the light from automobile head-lamps in city use. One of the many of recent design is made in a conical form of strong, flexible, transparent material. It is provided with a seam through the center making it collapsible when not in use. It is slipped on over the head-lamp and permits the uninterrupted

[55] *Illustrated World*, July, 1916, p. 676.
[56] *Illustrated World*, Feb., 1916, p. 822.
[57] *Pop. Mech.*, May, 1916, p. 722.
[58] *Gen. Rev.*, Dec., 1915, p. 1144.
[59] *Sci. Amer.*, Apr. 29, 1916, p. 446.

projection of the rays of the lamp through an opening in the bottom, but diffuses such rays as would ordinarily blind approaching drivers. So many dimmers for head-lamps have been brought out that a Massachusetts automobile club recently[60] carried out a series of tests to see how many dimming devices come within the specifications of the new state law. It was found that many commonly used appliances do not comply with the requirements. The club intends to continue these tests from time to time. By means of an outside set-screw focusing adjustment, an automobile search-lantern has been developed[61] which, it is claimed, can be used with any style of vacuum or gas-filled tungsten lamp and can be fixed instantly, without removal from its position, for any type of beam desired. A novel signal lamp for use by automobilists[62] consists of a brown celluloid hand inside of which is a tubular battery lamp with a special reflector which spreads the light uniformly through the hand. The device is held out on either side to indicate stopping or turning, just as in the daytime the human hand is used for this purpose.

Signal Lamps.—A device installed[63] in some of the government light houses, automatically replaces a burned-out lamp with a new one in a fraction of a second. Three lamps are arranged 120° apart about a circle. Only the one in focus is lighted. When it burns out an electromagnetic device operates, swinging one of the other lamps into place, where it is lighted. In places where oil is used as the illuminant, mantles have been almost universally adopted. Pressure burners are employed and a very high candlepower obtained. A new system[64] of night storm warnings has been worked out by the United States Weather Bureau. It consists of three lanterns in a vertical line instead of the two formerly employed. By this arrangement, it will be possible to indicate the expected direction of the wind to the nearest quadrant. Experiments by the bureau show that 4 ft. must separate the lanterns for every mile the observer is distant in order that each light may be seen separately by the naked eye.

[60] *Pop. Mech.*, Mar., 1916, p. 434.
[61] *Elec. World*, Oct. 16, 1915, p. 880.
[62] *Sci. Amer.*, July 8, 1916, p. 46.
[63] *Pop. Mech.*, May, 1916, p. 664.
[64] *Sci. Amer.*, Jan. 29, 1916, p. 121.

A high candlepower gas-filled tungsten lamp is being tried out as a source and the system will be first used on the Great Lakes.

In the triangulation work of the Coast and Geodetic Survey Department of the government,[65] it is necessary to establish bases which may be from 10 to 100 miles apart. To make the positions visible to the observers on clear days, sunlight is reflected from mirrors and on clear nights a specially constructed acetylene lamp has been used. To increase the effectiveness of this work, experiments have been made and a new electric lamp with a very highly concentrated filament in a gas-filled bulb has been developed. An automobile headlight is used as a reflector and the lamp is operated from dry cells. With two additional bulbs, three different intensities are obtained.

A new electric lantern[66] is shaped somewhat like a large watch, is provided with a bail and has an easel-like support for holding it in an upright position. It can be adjusted so that it produces a small searchlight beam or general illumination and it is operated by a flashlight battery.

Miners' Lamps.—Owing to two accidents resulting from the use of miners' electric lamps of the approved type, an order has been issued in England prohibiting the use, in such lamps, of spring terminals liable to be bent over. Electric lamps already in use must be refitted with rigid terminals. It is reported[67] that the use of electric lamps has not developed to the extent expected. Difficulties are still experienced which will have to be overcome before the old type of oil lamp is completely discarded.

WAR.

At the time of the last convention the present conflict had been going on for over a year and most of the apparatus used for illuminating purposes had become more or less standardized. The principal developments to be noted lie along the lines of restricted lighting, as a protection from air raids, and efforts to compensate for the scarcity of materials used in manufacturing illuminants and accessories.

Light Sources.—A German device[68] for the production of

[65] *Sci. Amer.*, Apr. 29, 1916, p. 454.
[66] *Pop. Mech.*, May, 1916, p. 754.
[67] *Elec. Times* (London), Oct. 28, 1915, p. 336.
[68] *Sci. Amer. Sup.*, Mar. 4, 1916, p. 148.
See also *Elec. World*, May 13, 1916, p. 1118.

colored flares to be used in transmitting signals consists of a receptacle containing the combustible liquid and a connecting gas reservoir. The particular color desired is obtained by adding suitable chemicals to the liquid and long or short flames may be produced by altering the gas pressure. It is said that the same apparatus is used for distributing asphyxiating gas and in portable form for projecting liquid fire. Modifications are used for illumination on the surface of water.

Owing to the facility with which it may be transported and its harmless and non-explosive character, carbide has been largely used[69] in the war. It has been estimated that the French alone have in use 10,000 of the portable searchlight type of acetylene lamps and over 200,000 of the small mine type. Oxy-acetylene lamps of the searchlight type are used for signalling and for the intense intermittent lighting of designated points.

A big increase is noted[70] in the use of miniature lamps employed for gun sights and reading instruments on battle ships and aeroplanes and also for the replacement of lamps broken in automobiles. The increase[71] in the use of flash lamps due to the war has been so great that two English firms have produced during the past year, no less than five times as many batteries as were produced in the entire United Kingdom prior to that time. Special types of lamps devised[72] to meet the needs of munition factories continue to appear.

In Switzerland[73] as in Germany the scarcity and cost of illuminating oil has led to an increase in the use of electricity for lighting purposes. Special arrangements have been made to help the poorer classes to have their homes wired.

Fittings.—Among the numerous fittings devised[74] as a result of the diminished illumination required in war times might be mentioned a screen made up of three conical metal rings coated dead black and placed one above the other. The idea is to obstruct the light emitted upwards and avoid the production of spots by light projected downward. The war has had a serious effect[75]

[69] *Acetylene Jour.*, Sept., 1915, p. 89.
[70] *Elec. World*, Feb. 26, 1916, p. 514.
[71] *Sci. Amer.*, May, 1916, p. 465.
[72] *Elec. Eng.* (London), Feb. 24, 1916, p. 69.
[73] *Elec. Eng.* (London), Mar. 23, 1916, p. 108.
[74] *Illum. Eng.* (London), Mar., 1916, p. 112.
[75] *Elec. News* (Canada), Feb. 15, 1916, p. 22.

on the production of glassware of all kinds for illuminating purposes. The shutting-off of the supply of potash from Germany as well as the difficulty of securing the oxides of antimony, zinc, and manganese has caused the discontinuance of the manufacture of certain qualities of glass by some factories. The demand for soda ash for use in manufacturing explosives has reduced the amount available for other purposes such as glass making. Further reference to the effect of war on the manufacture of glassware is noted under the title of "Globes, Reflectors and Fixtures." One of the indirect results of present conditions has been the development[76] of additional means for producing thorium from Monazite sand in this country to such an extent that it has been exported instead of imported as in the past.

The Prussian war office ordered[77] all barracks of the Prussian Army lighted by gas or electricity by November 1, 1915. In this manner a large amount of petroleum was liberated for the use of the civilian population.

Restricted Lighting.—The danger from raids by hostile aircraft has led England and Wales to adopt orders restricting lighting of highways, buildings and vehicles.[78-81]

Aviation Fields.—In order to help air pilots to make safe landings at night a type of lantern for aviation fields has been evolved in Germany.[82] The light backed by a suitable reflector is placed in a pit lined with firebrick having its upper end flush with the ground. Over this opening is placed an iron grating and upon this grid is set a wire frame covered with gauze which diffuses the light. At a distance the whole appears like a luminous globe. The shade is held up by a spiral spring which yields when struck. These lamps are spaced at regular intervals over the field and gas, oil, or electricity may be used as the illuminant. The shades have a maximum diameter of 18 in. and a height of only 1 ft. so that an even illumination is secured. On the other hand, the "patchwork" principle of concealment is spreading[83] and has been ap-

[76] *Gas Industry*, Jan., 1916, p. 160.
[77] *Elek. Zeit.*, Oct. 21, 1915, p. 557.
[78] *Jour. of Gas Ltg.*, Dec. 21, 1915, p. 6320.
[79] *Electrician*, Oct. 1, 1915, p. 943.
[80] *Pop. Mech.*, May, 1916, p. 729.
[81] *Jour. of Gas Ltg.*, Mar. 7, 1916, p. 535.
[82] *Sci. Amer.*, May 6, 1916, p. 463.
[83] *Sci. Amer.*, June 10, 1916, p. 371.

plied in a wide variety of cases. Thus to conceal aerodromes and similar objects the adjacent ground is cleared and the grass is scraped away at intervals leaving bare patches. The aerodrome itself is painted a patchwork of brown and green making identification from above very difficult. Another novel mode of concealment is employed in the latest zeppelins which are reported to have a coating of bright illuminating powder which reflects the sky. Owing to the menace of under-sea boats the proper identification of cargo and passenger vessels has become of increasing importance.[84] One company erects on deck large signs, bearing the name of the ship and its port, which are strongly illuminated at night. Another scheme[85] involves the use of automobile lamps to illuminate huge banners suspended from the gunwale with the information clearly painted on them.

FLOOD LIGHTING.

The availability of lighting units of high intensity together with specially designed reflectors has caused an enormous increase in that type of spectacular illumination which has become known as "flood lighting." In a discussion before the Chicago Section of this Society[86] reference was made to the possibility of the production of novel effects; the elimination of glare; operation at relatively low cost; use of flexible units; illumination of the entire front of a building instead of only parts of it, etc. As a medium for expressing civic pride this form of display lighting is becoming widely used.

Some public buildings using this form for temporary or permanent illumination were as follows: The Massachusetts State House in Boston was flooded[87] by means of two batteries of 500-watt lamps consisting of 74 units; two locations being used to reach the faces of the wings and also to throw light behind the columns in front of the building, thereby avoiding the flat appearance sometimes occurring when a building is lighted from the front only. Color effects were obtained by the use of gelatine screens. The new municipal building of Waterbury, Conn.,[88] was lighted to an intensity of 4 foot-candles by means of ten

[84] *Illum. Eng.* (London), Jan., 1916, p. 30.
[85] *Acetylene Jour.*, Dec., 1915, p. 211.
[86] *Elec. Rev. and W. E.*, Jan. 22, 1916, p. 141.
[87] *Ltg. Jour.*, Jan., 1916, p. 2.
[88] *Elec. World*, Dec. 25, 1916, p. 1419.

500-watt projector units mounted on a roof 150 ft. away. The illumination of the Court House and the tower of the Federal Building, Plymouth, Mass.;[89] ten projector units being employed. The entire exterior of the Arkansas State Capitol[90] is now illuminated by flood lighting through the use of thirty 500-watt units.

San Francisco has been experimenting[91] with flood lighting for use in connection with the new civic center, and at the Fourth of July celebration used eight 18-in. projectors provided with diffusing lenses to give an oblong shaped beam.[92] The main illumination is provided by 500-watt units located in the one case 250 ft. and in the other 300 ft. away. The new Kern County Court House at Fresno, Cal., has been flood-lighted.[93] An installation[94] of 300 projector units of the 500-watt size was installed to illuminate the Philadelphia City Hall.

Commercial Buildings.—Flood lighting[95] from other buildings is used to illuminate the new thirteen-story Hill Building in St. Paul, Minn. In Indianapolis[96] a fifteen-story bank building is flood-lighted above the third floor; 76 projectors are used to light the main front and 24 the other two sides, all being equipped with 250-watt units. The Columbus, Ohio,[97] Athletic Club was flood-lighted by means of twenty-four 500-watt projector units mounted on a platform at the top of two 65-ft. poles.

The effective illumination of stores[98] has been accomplished by lamps and projectors located on the buildings themselves.[99]

Monuments.—The most unique proposal in connection with flood lighting[100] is that of illuminating the Statue of Liberty in New York Harbor, to be financed by popular and congressional subscriptions. The flood lighting of monuments and statues[101]

[89] *Elec. Rev. and W. E.*, Apr. 8, 1916, p. 651.
[90] *Elec. Rev. and W. E.*, Apr. 22, 1916, p. 709.
[91] *Elec. World*, July 15, 1916, p. 150.
[92] *Elec. World*, July 1, 1916, p. 31.
[93] *Elec. World*, Apr. 8, 1916, p. 809.
[94] *Elec. World*, July 22, 1916, p. 187.
[95] *Elec. World*, Mar. 25, 1916, p. 714.
[96] *Elec. Merchandise*, Jan., 1916, p. 35.
[97] *Elec. World*, Mar. 4, 1916, p. 549.
[98] *Elec. City Mag.*, Nov., 1915, p. 7.
[99] *Elec. Rev. and W. E.*, May 13, 1916, p. 840.
[100] *Elec. Rev. and W. E.*, May 27, 1916, p. 951.
[101] *Elec. World*, June 24, 1916, p. 1475.

has been given an enormous impetus since the announcement of this project, other notable installations were the Soldiers' Monument of Indianapolis, Ind.,[102] flood lighted by means of beams from 100 projectors placed on the roofs of adjacent buildings and the flood lighting of the American Niagara Falls,[103] New York, by fifty reflector units, the light penetrating even the darkest parts of the rolling mists.

Amusements.—The illumination of Sheepshead Bay[104] automobile speedway, New York, marks the most pretentious experiment tried for night-time outdoor sports and races. The interior field of 160 acres is lighted by 224 flood-light projectors on poles spaced 100 ft. apart on alternate sides of the track, the lamp height being 30 ft. above the track. The space just opposite the grandstand is further illuminated to about 3 foot-candles by 114 additional projectors located at the top of the stand. The projectors along the track are arranged so that they can be readily turned upon the race course, but the light sources are hidden from the eyes of the drivers, projecting their beams in the same direction as the speeding machines.

Patterned after the spectacular effects obtained at the Panama-Pacific Exposition the municipal Christmas tree at Chicago[105] was illuminated entirely by five large searchlights and a number of smaller units. Color screens were used on some of the reflectors. Outdoor theatres,[106] stadiums, rinks, toboggan slides, etc., have been successfully illuminated by flood-lighting units.

The practicability of flood lighting for bathing beaches[107] has been amply demonstrated in Chicago. At Diversy Beach eighteen projectors with 500-watt lamps are used mounted on a frame work. Each projector has a swiveling base for adjustment. The installation is on the top of the highest bath house and between 6 and 7 acres are illuminated. It is proposed to add a tower on which will be mounted a concentrated flood-lighting projector which normally will be directed on the diving platform but will be turned at will to aid in rescue work if necessary. Another

[102] *Elec. World,* July 15, 1916, p. 120.
[103] *Elec. Rev. and W. E.,* June 24, 1916, p. 1143.
[104] *Ltg. Jour.,* June, 1916, p. 117.
[105] *Elec. Rev. and W. E.,* Jan. 1, 1916.
[106] *Elec. Rev. and W. E.,* Apr. 8, 1916, p. 651.
[107] *Elec. Rev. and W. E.,* July 8, 1916, p. 69.

beach employs two steel towers, 85 ft. high, 775 ft. apart and 100 ft. from the edge of the water. Ten projectors will be mounted on platforms on the top of the towers and 1,000-watt lamps will be used. The area illuminated will be 11 or 12 acres. Among other such installations[108] are those at Seal Beach, Cal.; Hot Springs, Ark.,[109] and Trenton, N. J.[110]

Flags.—A big 30-ft. silk flag on top of a twenty-story building in Chicago[111] has been satisfactorily flood lighted by using two 500-watt units trained on the blue star field and from two to four 250-watt units to light the stripes. A novel method of illuminating a flag mounted on a private residence consists[112] in the use of two tungsten lamps in reflectors placed on the piazza roof and invisible from the street.

Industrial flood-lighting is pushing its way[113] into a large number of varied activities. Night work in the harvesting of ice is not new but the problem of satisfactorily lighting an ice field has in the past, been difficult. Very good results have been obtained using portable 1,000-watt lamps in projectors closed with a wire glass front making them rugged, storm and weather proof. Flood lighting was used to advantage[114] when the gruesome task of recovering bodies from the steamer Eastland had to be carried on at night. Flood-lighting projectors are being used in connection with night work on the construction of buildings,[115] for loading operations at wharves,[116] and for the illumination of signs.[117] Placement of the source in front of or at the edge of the sign is still an open question.

STREET LIGHTING.

As the Panama-Pacific Exposition was a striking proof of the value of employing an illuminating engineer for the solution of a specific lighting problem, so the street lighting system of Milwaukee and other well-known installations, has already furnished

[108] *Sci. Amer.*, July 15, 1916, p. 57.
[109] *Ltg. Jour.*, July, 1916, p. 148.
[110] *Elec. Rev. and W. E.*, Aug. 5, 1916, p. 243.
[111] *Elec. World*, May 20, 1916, p. 1173.
[112] *Elec. Rev. and W. E.*, Aug. 5, 1916, p. 228.
[113] *Elec. Age*, Feb., 1916, p. 63.
[114] *Elec. Rev. and W. E.*, Jan. 15, 1916, p. 100.
[115] *Elec. World*, Apr. 1, 1916, p. 795.
[116] *Elec. World*, July 22, 1916, p. 199.
[117] *Elec. World*, Jan. 22, 1916, p. 210.

an instructive example of the fact that the scientific application of the principles of illuminating engineering produces results commensurate with the expenditure.

In street lighting by electricity, the most marked evolution[118] has been the rapid extension of the use of gas-filled tungsten high power lamps in new installations and in replacing arc lamps in old installations. One of the features of these lamps is the readiness with which they may be adapted to different types of standards and special fixtures. In this connection it may be said that while the majority of lamps in use are of the series type, increasing numbers of multiple lamps are being used, especially in well-lighted districts.

As in interior illumination the tendency in street lighting toward a higher intensity of illumination is still growing. Since 1907 the average candlepower of incandescent lamps used for this purpose has increased 300 per cent. The increase in night traffic due to the use of automobiles has awakened an interest[119] in the lighting of highways and this subject has been investigated by a committee of the National Electric Light Association. Letters were written to the Secretary of each state in the Union asking for information regarding highway illumination paid for by the state or counties. It was found that in 90 per cent. of the states no money had ever been expended for this purpose and no consideration had ever been given to the subject.

White Ways.—The installation of ornamental display or "White Way" lighting still continues. Some representative installations[120] are those at La Porte, Ind., Brockport, N. Y., Racine, Wis., Vincennes, Ind.,[121] Sheboygan, Wis.,[122] St. Louis, Mo.,[123] Peru, Ind.,[124] and Ennis, Texas.

Developments in street lighting throughout the country may be seen from a partial record of new installations:

[118] Report of Lamp Committee, N. E. L. A., May 22, 1916.

[119] Report of Sub-Committee on Municipal and Highway Lighting, N. E. L. A., May 22, 1916.

[120] *Municipal Jour.*, Jan. 13, 1916, p. 51.

[121] *Elec. Rev. and W. E.*, Jan. 1, 1916, p. 25.

[122] *Municipal Jour.*, Jan. 1, 1916, p. 769.

[123] *Amer. Gas Lt. Jour.*, Oct. 11, 1915, p. 238.

[124] *Elec. Rev. and W. E.*, Aug. 5, 1916, p. 231.

The new Market Street luminous arc installation has been inaugurated[125] at San Francisco. Fifteen blocks are included. Ornamental poles at intervals of 110 feet carry three 6.6 ampere lamps enclosed in sectional globes with special glassware. The new system gives fifteen times the illumination formerly obtained. A set of plans for lighting the Civic Center has been prepared.[126]

The type of ornamental luminous arc lamps used for lighting Market Street has also been adopted in various other localities.[127] Two types of street lighting standards have been adopted[128] at Riverside, Cal., one for the business district carrying 3 lamps, and one for the residential district surmounted by one lamp. The former has a total height of 12 feet and is equipped with two 60-watt lamps and one 40-watt lamp. The residence standard is 9 ft. 6 in. high and carries a 60-watt lamp.

A trial of new highway lighting units[129] has been made on the California State highway between Chico and Red Bluff. Luminous arc lamps of the 4-ampere size spaced 650 ft. apart and hung 25 ft. above the road have been used.

It has been planned to illuminate[130] some 4 miles of the Lincoln highway leading into Oakland, Cal. A test of the various methods of illumination best suited to motoring will be made. This forms the third section of the highway to the illuminated, the other parts being at Aurora, Ill., and Salt Lake City, Utah. Eighteen miles of the highway running from the last city to Garfield, Utah, have been lighted by means of lamps placed 50 to the mile.[131] It is claimed that this is the first section outside of the corporate limits of a municipality to be lighted.

A law passed last year[132] by the Utah Legislature providing for the creation of lighting-improvement districts in cities has

[125] *Elec. World*, Apr. 1, 1916, p. 749.

[126] *Ibid.*, Apr. 29, 1916, p. 1013.

[127] *Jour. Elec. Pr. and Gas*, June 17, 1916, p. 743.

[128] *Elec. World*, July 8, 1916, p. 89.

[129] *Jour. Elec. Pr. and Gas*, Oct. 20, 1915, p. 348.

[130] *Elec. Rev. and W. E.*, June 3, 1916, p. 1016.

[131] *Elec. Rev. and W. E.*, Feb. 26, 1916, p. 363.

[132] Progress Report, TRANS. *I. E. S.*, Oct., 1915, p. 558.

been taken advantage of[133] by Salt Lake City. Four-ampere pendant type luminous arc lamps to the number of 218 have been installed on the trolley poles which are 100 ft. apart in a district comprising practically all of the business section of the city excepting one street which is included in a separate district to have more elaborate lighting.

During the winter the city of Milwaukee, Wis., has completed[134] the first section of the new street lighting system mentioned in last year's report. Most of the work is being done this year and the remainder will be carried out in 1917, a total of 6,800 lamp posts being called for. A preliminary installation of 176 lighting units on about 8 miles of streets showed the possibilities of the plan and was a decided factor in the adoption of the system as a whole. A feature of this system is that it is designed when fully completed, to give uniform illumination on each street. This is to be accomplished by a scientific selection of lamps, fixtures, mounting heights, and spacings and by the use of a specially designed refractory globe which reduces illumination below and near the lamps and increases it between units. In determining spacing it was found that six times the mounting height for down-town streets, eight times for important thoroughfares and in secondary business streets, and twelve times for residence streets using the refractor globe, gave the desired uniform illumination. A single type of lamp fixture is used throughout and from the external appearance it is impossible to tell whether it contains a gas or an electric lamp. The illumination values are as follows:

Nature of street	Foot-candle intensity
Alleys and outlying streets	0.01
Residence streets	0.03
Subsidiary thoroughfares	0.06
Main thoroughfares	0.12
Promenades and principal business streets	0.50

What is claimed to be the first "indeterminate" street lighting

[133] *Elec. World,* June 3, 1916, p. 1313.

[134] *Municipal Jour.,* May 11, 1916, p. 647.
Elec. World, Mar. 18, 1916, p. 645.

contract ever offered a city has been submitted[135] to a committee of the City Common Council of Racine, Wis. The terms permit the company to make expenses and 6 per cent. on the money invested.

In Chicago between June 1, 1915 and June 1, 1916, 5,400 of the 600-candlepower 300-watt series gas-filled incandescent lamps were placed in service. These were used to replace a number of flame arcs which were transferred to new locations and 1,680 enclosed arcs. The greater number of new lamps were installed at new locations. Construction work was completed for 800 additional units of this type which were to be put in service in June. During the past year 1,700 new 100-candlepower 4-ampere series gas-filled tungsten lamps were placed in service on underground circuits connected to armored cable laid in the parkway without additional protection.

The number of gas lamps in service has been reduced to 7,500, 1,248 of which are of an ornamental type equipped with diffusing glassware. All gas lamps are provided with inverted mantles and consume 3 cu. ft. per hour.

Indianapolis, Ind., has installed 2,632 series flame arc lamps and 449 gas-filled tungsten lamps.[136] The former are used for lighting large areas, the latter for small areas requiring only a single unit.

Jefferson, Ind., has replaced arc lamps[137] by gas-filled tungsten lamps of 400-, 250- and 80-candlepower sizes, about 300 lamps being used. A boulevard system is to be installed in Cincinnati, Ohio,[138] on Sixth Street, consisting of 70 lamps, 14 to the block. The standards are to be 12 ft. high.

A new municipal lighting system has been designed[139] by an illuminating engineer and has been accepted by the Lighting Committee of the City Council of Marion, Ohio. The layout includes the placing of moderate sized lamps to act as beacons on the pikes leading into the city. These should be of considerable assistance to automobilists.

[135] *Elec. Rev. and W. E.*, Dec. 25, 1916, p. 1144.

[136] *Ltg. Jour.*, June, 1916, p. 126.

[137] *Elec. Rev. and W. E.*, Oct. 23, 1915, p. 754.

[138] *Elec. World*, Feb. 26, 1916, p. 511.

[139] *Municipal Jour.*, June 1, 1916, p. 769.

Work has commenced in New Orleans, La., on the installation of a new street lighting system by which all the principal avenues, streets, parks and public highways will be illuminated by means of ornamental cast-iron single-light standards surmounted by 250-candlepower gas-filled series tungsten lamps. Approximately 3,200 series magnetite 5½-ampere arc lamps equipped with prismatic glass refractors will also be used for the general lighting of the streets.

Additions to existing installations have been made in Washington, D. C., Philadelphia, Pa., Boston, Mass., New York City, and other large municipalities.

A very good description of the street lighting system of New York City is to be found in the report of the Lamp Committee N. E. L. A., May, 1916. All arc lamps for street lighting have been replaced with gas-filled tungsten lamps, the 300- and 400-watt multiple and the 400-candlepower series lamps having been standardized. In general these lamps are installed at the mounting heights of the arc lamps which they replace. Data on illumination in the residential streets has been obtained indicating a maximum of 0.347 and a minimum of 0.01 and an average of 0.068 foot-candle horizontal illumination at the street surface.

There has been a considerable extension of street lighting in Canada and foreign countries, as may be seen from the following instances:

Montreal has installed an ornamental lighting system[140] on a number of the most important streets, using 6.6-ampere arc lamps. Arrangements have been made[141] to reorganize the lighting of the Champs de Mars. One hundred-watt gas-filled tungsten units will be used at the corners and a 300-watt unit at the center.

In St. Hilare, 80-candlepower gas-filled tungsten lamps have been provided[142] for street lighting.

The arc lamp system of Renfrew has been replaced in the main business district by 750-candlepower gas-filled tungsten lamps mounted on cast-iron standards.

[140] *Elec. News* (Canada), Mar. 15, 1916, p. 23.

[141] *Ibid.*, June 1, 1916, p. 80.

[142] *Ibid.*, Oct. 1, 1915, p. 56.

Extensions and improvements in the street lighting system of Sarnia have been planned[143] by the Hydro-Electric Power Commission of Ontario, and may thus be taken as representative of Canadian practice in electric lighting. Eighty-eight of the 1,000-candlepower gas-filled tungsten lamps will be used on the main street, mounted on combination tubular steel trolley poles. These poles are 110 ft. apart and the lamps will be placed on both sides of the street and at a height of 16 ft. above the pavement. Each lamp is to have a glass reflector with special distributing features. Four hundred-candlepower lamps will be used on some of the side streets in the middle of the street and at 400-ft. intervals. The height of suspension in these cases will be 25 ft.

A new street lighting contract[144] with the city of Vancouver, B. C., provides for the replacement of all old type carbon-arc lamps by gas-filled tungsten units of 250-, 400- and 600-candlepower sizes. The last named are to be used on car-line streets; the first named in ornamental lighting standards and the others in residential streets.

London, England, is replacing arc lamps with gas-filled tungsten lamps[145] of 300- and 500-watt capacity suspended from the arc light poles.

The present lighting in Liverpool, England, is given by 12,513 gas-mantle lamps, 2,677 flat-flame gas lamps, 551 electric lamps and 93 oil lamps. This shows a reduction due to restricted lighting of 7,208 gas lamps, all electric arc lamps and 578 incandescent lamps.

Experiments have been conducted[146] in Rome, Brescia, Parma and Naples, Italy, to determine the relative advantages of gas-filled tungsten lamps as compared to arc lamps.

Investigations.—In last years report[147] reference was made to an investigation of the street lighting problem carried on under the joint auspices of the National Electric Light Association and the Association of Edison Illuminating Companies, the experi-

[143] *Elec. News* (Canada), Oct. 1, 1915, p. 59.

[144] *Ibid.,* June 15, 1916, p. 22.

[145] *Elec. Times,* May 25, 1916, p. 384.

[146] *Elettro Tecnica,* Feb. 25, 1916, p. 114.

[147] Progress Report, TRANS. I. E. S., Oct., 1915, p. 542.

ments being made in New York City. A similar investigation has been carried out in Philadelphia and reported to this Society.[148] One of the most important conclusions arrived at was that "the total flux of light produced by a street illuminant which is reasonably well adapted to street lighting is likely to be a pretty fair index of its illuminating value for street lighting purposes; that while characteristic of distribution and other factors are important, yet any basis of rating, which leads to the conclusion that the order of value of street illuminants is radically different from the total light produced, should be accepted with caution." As a result of psychological tests, the following is given as a conclusion, "the conclusion seems therefore warranted that, other things being equal, non-uniform illumination (of the type described) is more conducive than uniform illumination (of the type described) to the safety of the pedestrian."

Reference should also be made to the report on street lighting submitted by the Committee on Glare and printed in the TRANSACTIONS.[149]

OTHER EXTERIOR ILLUMINATION.

Farm lighting has grown so extensively in recent years that it has been stated[150] that there are probably 100 or more manufacturers and assemblers of equipment for this purpose in the United States to-day and the number is increasing. Additional data[151] on daylight illumination and on the intensity and duration of twilight have been reported to this Society. Thus for the location at which the measurements were made (Mount Weather, Va.) it was shown that in December the noon intensity on a horizontal surface averaged about 4,300 foot-candles as compared with 9,600 foot-candles in June. Marked effects were found in decreased illumination when haze or smoke was present.

By cutting cubical pockets in the heavy walls on the sides of the dam across the Bronx valley, and inserting lantern boxes, the state highway has been lighted[152] in a novel but satisfactory

148 TRANS. I. E. S., June 10, 1916, p. 489.

149 *Ibid.*, p. 518.

150 *Elec. Rev. and W. E.*, Jan. 15, 1916, p. 101.

151 TRANS. I. E. S., May 1, 1916, p. 399.

152 *Pop. Sci. Mo.*, June, 1916, p. 905.

manner. Abroad[153] factories that are engaged in the manufacture of munitions of war have almost invariably installed exterior lighting systems to aid the watchman in patrolling the plants. In Germany[154] there has been a considerable development in the methods of illuminating hangars so that they can be readily recognized by air men at night. Further reference to this subject is made under the caption "War."

The dedication of the new Massachusetts Institute of Technology buildings[155] was made the occasion of some elaborate lighting effects. Spot and flood lighting was accomplished by means of thirty-four 1,000-watt stereoptican projectors installed at approximately 3-ft. intervals on the roof of one of the buildings. Twelve projectors were equipped with blue, nine with red, and nine with green color-screens. A drama participated in by 500 performers was given on a central platform, below the floor level of which were four 1,000-watt projectors each in a pit with a glass cover. These were for lighting effects in connection with dancing and additional units were used for illuminating jets of water in connection with water dances. Six 500-watt projectors without screens were used for spot lighting the court and two 60-ampere direct current searchlights loaned by the U. S. Navy lighted the various craft in the river basin. The permanent lighting is arranged with lamps so shaded as to throw the light on the building facades.

Sports.—The use of artificial lighting for sports has increased considerably since the introduction of high power units.[156] In the lighting of tennis courts the question whether the center line or side line method is the better is being experimented with.

The use of two 100-watt projector units has enabled extra hours of practice for the football squad of a big university.

The lighting of a trap-shooting ground for night use might seem a difficult proposition but it has been successfully accomplished in several instances. The requirements are peculiar. Shooting is usually done at 16 to 18 yards rise and at the traps

[153] *Elec. World*, Jan. 22, 1916, p. 210.

[154] *Zeit. f. Bel.*, Dec., 1915, p. 131.

[155] *Elec. World*, June 17, 1916, p. 1437.

[156] *Elec. World*, June 24, 1916, p. 1462.

the lighting must be rather brilliant over a semi-circular area of something like 40 yards radius. In the one case[157] a strong general illumination is produced by lamps high and back of the shooter while a bank of screened reflectors just in front of the traps, flood light the targets as soon as they appear. In another case[158] a gun club has had installed at its traps a battery of eight 250-watt lamps of the concentrated stereoptican type in special reflectors mounted on a platform 15 ft. high. The reflectors are elevated at about a 4°-angle above the horizontal and the lights converge on one another each giving about a 20°-angle of light. In this case it is claimed that the night shooting is even better than the day, as there is less diversion of one's attention from the work at hand.

Flag Lighting.—The wave of patriotism which has recently swept the country has stimulated interest in the national emblem. The use of electric self-luminous flags and of flood-lighted flags has grown tremendously. The electric self-lighting flag idea has spread from business buildings, factories, shops, schools, etc., to private residences in many cities in the middle west.[159] At Athens, Ga., the presentation and unveiling of an electric flag was made the occasion of a patriotic celebration.[160] A very large electric flag has been erected in Chicago.[161] Its dimensions are 56 ft. by 54 ft. and 2,933 lamps of the 15-watt size are used in its equipment.

Sign Lighting.—The spectacular effects which may be obtained[162] by the use of colored lamps and plaster casts are being used more and more for advertising purposes. Sign lighting grows in novel treatment. One of the latest signs which imitates[163] the sky-rockets of old-fashioned fire works not only utilizes lights but also compressed air to give the hissing sound of the escaping rocket.

[157] *Elec. World,* June 24, 1916, p. 1450.

[158] *Elec. Rev. and W. E.,* June 10, 1916, p. 1064.

[159] *Elec. World,* Feb. 5, 1916, p. 327.

[160] *Elec. World,* Apr. 29, 1916, p. 1011.

[161] *Signs of the Times,* Apr., 1916, p. 9.

[162] *Elec. World,* Dec. 25, 1915, p. 1420.

[163] *Elec. World,* May 15, 1916, p. 1109.

The use of signs to advertise church services[164] has been slowly growing and a recent installation was inaugurated by a regular religious ceremony. The sign in question is in operation every day from noon to midnight. An echo of the spectacular lighting at the Panama Pacific Exposition is to be found[165] in the use of the idea of scintillating jewels such as those used in the Tower of Jewels. This idea was adopted in the lighting of the municipal Christmas tree in Chicago and has also been employed in the display lighting of a moving picture theatre.

A change in the flood-lighting method of bill-board illumination[166] consists in the use of a single upright standard carrying a suitable unit with reflector, in place of the ordinary method of using border angle reflectors. This has resulted in a considerable saving in cost.

INTERIOR ILLUMINATION.

The possibilities in the use of light properly graduated and directed to produce desired effects in interior illumination are being recognized.[167] It has been found that an alteration in the illumination in a room may produce a change in the apparent distance of a wall as much as 10 per cent. A patent has been taken out[168] for a system of lighting in which the light source is placed in an opening in the wall so that the rays of the lamp may be shed into two or three rooms or compartments at the same time. It is expected that sufficient illumination will be obtained to meet the requirements of bed-rooms and hallways. Frosted or ribbed glass is used to protect the openings to each room and shutters are provided to cut off the light when desired.

Office Buildings.—An interesting illustration[169] of development in the lighting of a modern office building by gas is to be found in the illumination of the new Consolidated Gas Building in New York City. Experiments extending over a considerable length of time were made to determine the system to be employed

[164] *N. E. L. A. Bul.*, May, 1916, p. 383.

[165] *Elec. City Mag.*, Feb., 1916, pp. 12 and 17.

[166] *Elec. World*, Nov. 27, 1915, p. 1201.

[167] *Gas Age*, Mar. 1, 1916, p. 277.

[168] *Sci. Amer.*, Feb. 26, 1916, p. 217.

[169] *Gas Age*, Feb. 15, 1916, p. 197.

and the semi-indirect method was finally chosen. Experimental work was also done to determine the design of fixture to be employed, the burner equipment with which it should be supplied, the glassware to be used, and the ignition system most desirable. In the following table are given the illumination values in some of the principle locations:

Bookkeeper's space	6.0 to 7.0 foot-candles
Drafting room	7.0 to 8.0 foot-candles
General office space	4.0 to 5.0 foot-candles
Private office space	3.0 to 4.0 foot-candles
Halls	1.0 to 1.5 foot-candles

The lighting[170] of the new Equitable Building in New York City, the largest office building in the world, indicates the trend of practice for this type of illuminating engineering problem. In the ground floor corridors the indirect cove lighting is supplemented by light from pendent fixtures consisting of horizontal rings studded with radially projected frosted bulbs. Corridors and other passageways on the upper floors are illuminated by canopy-type direct-lighting fixtures. In the offices convertible fixtures are used which may be set to give either direct or semi-indirect lighting by means of a movable lower member of the fixture. In the Banker's Club which occupies all of three floors the fixtures are decorative and are made to harmonize with the furniture and architecture. Table lamps and chandeliers provide direct lighting while general illumination is furnished by cove lighting from lamps concealed in cornices around the columns and walls. In the restaurant in the basement illuminated translucent glass cornices around the columns furnish indirect lighting.

Stores.—A candy and catering store in the west[171] has a number of unique features in its lighting equipment. The forward half of the store is lighted by mirror-lined trough reflectors in coves while the show cases have specially designed reflectors carrying low wattage lamps to avoid heating the candles. The rear half of the store is lighted by means of stereoptican lamps in shallow bowls mounted on pedestals. A reflector cuts the direct rays of light from the side walls throwing it upward and toward the center of the room. The effect is that of the cove

[170] *Elec. World,* Jan. 15, 1916, p. 137.

[171] *Jour. of Elec. Pr. and Gas,* Jan. 22, 1916, p. 63.

system. The average intensity is given as 2 foot-candles. The banquet room is lighted by projectors of heavily plated spun brass equipped with stereoptican lamps. The ceiling is divided into four panels, in the center of each being a compo-plaque overlaid with a luminous foil stained in different colors. There is a curve to each plaque so designed that when a pencil of light from the projector strikes its surface, the rays are deflected and diffused at the proper angle. The inside of each reflector holder is painted in stripes of red, green and blue and these colors in turn are reflected to the upper edge of each projector. There is no glare and the beams of light are invisible except when the diners are smoking. The average intensity on the floor is given as 1.6 foot-candles with a wattage about 1.2 watts per square foot.

In a western bank[172] a combination of cove lighting in the public lobby and fixture lighting over the teller's cages and working space has produced a very satisfactory artistic and utilitarian illumination.

Show Windows.—One result of the two "prosperity weeks"[173] has been a marked improvement in window lighting. A new system[174] of interchangeable show-window lighting has been introduced which permits the easy installation or removal of lights to suit any particular class of merchandise displayed. The result is accomplished by means of properly insulated current-carrying strips to which contact is made through plugs or hooks.

Factories.—The report of the English Departmental Committee on Lighting in Factories and Work Shops is discussed under the heading "Legislation" as is also the Memorandum of the Health of Munition Works Committee. By installing[175] a special night lighting system using low wattage lamps a considerable saving has been accomplished in a factory where an inspection showed the regular system was being used when only a few lamps were needed. An interesting test[176] of the effect of adding artificial light to daylight was made in a shop where machine work predominates. It was found that as the natural light decreased the work fell off. On adding artificial light on a dark day the work

[172] *Elec. World*, Mar. 11, 1916, p. 608.
[173] *Elec. Rev. and W. E.*, Dec. 25, 1915, p. 1143.
[174] *Signs of the Times*, May, 1916, p. 10.
[175] *Elec. Rev. and W. E.*, Jan. 1, 1916, p. 34.
[176] *Ltg. Jour.*, Apr., 1916, p. 79.

increased but decreased when the artificial light was added on a bright day. It was suggested that in the latter case the combination of two classes of lighting differing in color content requires an effort on the part of the eye to keep adjusted to momentarily changing conditions.

Schools and Churches.—The work of the Committee on School Lighting[177] is beginning to bear fruit as evidenced by the marked improvement in the methods of lighting used in some recently erected schools.

The number of new church installations described in the technical press indicates a decided awakening of those in charge to the value of good lighting. By using trough reflectors[178] concealed between the mouldings of the arches at the points where the latter spring from the pillar-capitols, a church in England gets the effect of indirect lighting although the lights are visible to those leaving the auditorium. The value of the illumination on the working plane is given as between 2½ to 3 foot-candles.

Hospitals.—In connection with X-ray surgery in hospitals it has in the past been customary for the surgeon to work either in darkness or, if in the light, to depend upon an assistant who, alone in a position to see the X-ray images on the screen, guides him in his work. Owing to the disadvantages of both methods surgeons rarely attempt to operate under the guidance of the fluorescent screen and X-rays, relying almost wholly on radiographs. A new method[179] has been worked out involving the law of simultaneous contrast. The operating room is illuminated by an intense red light of considerable purity. Thus the active phases of an operation are executed under a red light while the X-ray examinations of the body in the region of the operation are made in the greenish light of the fluorescent screen. The method has been used for several months and while the illumination obtained is not high, it has been found to be satisfactory.

Art Galleries and Museums.—An appreciation of the possibilities of applied illuminating engineering is extending[180] even to private art galleries. Thus in one instance it was found possible to replace an old and unsatisfactory trough system by a series

[177] *Ltg. Jour.*, June, 1916, p. 123.
[178] *Elec. Times* (London), Apr. 20, 1916, p. 291.
[179] *Sci. Amer.*, Feb. 19, 1916, p. 195.
[180] *Elec. World*, Mar. 25, 1916, p. 710.

of stereopticon reflectors placed above the skylight. An intensity of about 6.5 foot-candles was obtained, quite uniformly distributed over the wall space occupied by the pictures and the angle at which the light is received is such that there is no direct reflection from the surface of the canvas to the eye of the observer. The lighting of art galleries has occupied the attention of illuminating engineers for a number of years but recently attention has been called to the problems involved in the proper lighting of museums[181] and particularly those of natural history. The colors of some birds are so evanescent that they will not stand exposure to any light. The same is true of butterflies. The coats of such animals as deer may be ruined and the color of black-skinned animals may be altered as the result of exposure to light. The problem is complicated in many existing museums owing to the expense and difficulty of installing new and up-to-date installations. The problem is further complicated by lack of data as to just what quality of light would be best to minimize the effect of fading, etc. Attention should be called to the lighting of the new Cleveland Museum of Art, a description of which is to be presented at this convention.

Auditoriums and Theatres.—The arena of the new auditorium at Oakland, Cal.,[182] is illuminated by a set of what are claimed to be the largest semi-indirect fixtures ever built and placed in one room. They are 10 ft. in diameter and suspended 60 ft. from the floor. A total of 44 kilowatts are used in the eight fixtures. The average illumination on a reading plane is 3.2 foot-candles. The theatre is illuminated by a center skylight behind which are placed gas-filled tungsten lamps in special mirrored reflectors. The ceiling decorations are brought out by means of cove lighting. In the art gallery provision has been made for a large number of receptacles to permit of the individual lighting of the pictures. The main illumination in this section is through the skylight. In the ball room the illumination on the reading plane is 2.7 foot-candles produced by lamps in reflectors placed above moss-amber glass.

A new departure[183] in stage lighting is to be found in the re-

[181] *N. E. L. A. Bul.*, May, 1916, p. 384.
[182] *Jour. Elec. Pr. and Gas*, Apr. 1, 1916, p. 257.
[183] *Ltg. Jour.*, Oct., 1915, p. 217.

placement of the old footlights by a string of lights with suitable reflectors placed on the stage side of a front drop curtain. This curtain can be raised or lowered to meet the requirements of different scenes.

The growth of the moving picture business is evidenced by the number and character of new theatres built for this purpose. The problem of lighting[184] such theatres is so different from that of the ordinary playhouse that where it has been turned over to him, the illuminating engineer has had an opportunity to work out many novel ideas in lighting. The intermittent coming and going of patrons in general requires continuous illumination to permit leaving and finding of seats without difficulty. In some cases the screen projection is arranged so that the pictures are distinct even with a full illumination of the auditorium, but in most cases a twilight illumination is maintained by shaded, and frequently, colored lights. Such lights are apt to be distracting and a novel manner of eliminating this difficulty has been employed in a recently fitted up photo-play house by gradually diminishing the illumination from a full daylight effect at the entrance to deep twilight at the screen. This is accomplished by lamps concealed in coves which illuminate the ceiling. The gradation was so planned that the eye adapts itself to a smaller and smaller amount of lighting without the change being noticeable. Another novelty of this installation is found in the entrance lighting where an application has been made of a color change effect[185] produced by using three primary colors which pass through a cycle of varying intensities so arranged, however, that the total flux of light remains practically constant. Each color varies from instant to instant giving a resulting effect which constantly changes.

Sports.—Two sets of lighting units were used recently[186] to light a boxing match, one to give photographic results and the other to correct the color effect of the mercury arcs and make the resulting light better adapted for the spectacle. For the ordinary lighting an inverted cone 9 ft. in diameter and carrying 300 sign receptacles fitted with 25- and 40-watt clear bulb tungsten

[184] *Elec. City Mag.*, Feb., 1916, p. 17.

[185] "Color and Its Applications," New York, D. Van Nostrand Co., 1915, p. 274.

[186] *Elec. World*, July 15, 1916, p. 122.

lamps was suspended so that its bottom was 16 ft. from the floor. Five frames each containing eight mercury-vapor lamps were used for the photographic lighting together with 10 arc lamps to bring in the red color component. The effective area of the ring was 576 sq. ft. and the energy consumption for illuminating purposes was 65 kilowatts or 110 watts per square foot. An armory has been made available for indoor tennis[187] by installing a proper system of lighting using high power lamps.

Railways.—An improved system of lighting has been standardized for Pullman cars,[188] and the changes have resulted in a large increase of illumination with the same power consumption. A higher mounting with the lamp filament completely covered has reduced glare. There has been a big reduction in maintenance and cleaning. One hundred-watt tungsten lamps are used in 12-in. bowls and photometric tests have given an average of 7.5 foot-candles on a plane 36 in. from the floor. The problem of lighting a railway roundhouse[189] involves many unusual features including not only the proper spacing and distribution of the sources but also their protection from the corroding action of gas and their proper cleaning. A system has been worked out and standardized by a Canadian railway which uses specially designed reflectors similar to those used as headlights on interurban electric cars. A semaphore lens is employed as the front glass of the reflector and this diffuses the light and cuts off the glare as well as offering a surface easily kept clean. These lights are arranged in sets, one set lighting the engines, another the turntable and pit, another serving for general illumination, and another for portable use. The system has been found to have great advantages over the drop light equipment formerly used. A new system of lighting installed in the case of one of the railway lines of New England[190] employs 10 tungsten lamps fitted with heavy density, opal-glass reflectors arranged along the center line of the car roof. The system replaces one using 42 smaller wattage lamps mounted in flush sockets without reflectors located under the lower decks and on each side of the car.

[187] *Elec. Rev. and W. E.*, Oct. 30, 1915, p. 788.

[188] *Railway Elec. Eng.*, June, 1916, p. 400.

[189] *Elec. News* (Canada), June 1, 1916, p. 62.

[190] *Elec. Ry. Jour.*, Oct. 30, 1915, p. 918.

Houses.—An improved form of bath-room lighting[191] consists in the use of tubular frosted case lamps mounted on the sides of the mirror. When not lighted the lamps are not conspicuous since in appearance they do not differ much from the white glass towel bars.

GLOBES, REFLECTORS AND FIXTURES.

Fixtures.—The fluctuations in the design of lighting fixtures seem almost as great as those in the types of automobiles. The shower and the dome of yesterday are superseded by the totally indirect fixture of to-day and the latter may be superseded by the semi-indirect fixture of tomorrow. But there is a growing tendency[192] on the part of manufacturers to recognize the individual requirements of specific locations such as stores, halls, offices, living- and dining-rooms, corridors, etc., and to design fixtures which shall be appropriate for each specific need. For the usual commercial and residential work the semi-indirect fixture has become[193] the predominating type for both classes of service, gas and electricity, and efforts are being made[194] to produce fixtures and glassware which will harmonize where the two illuminants are used in the same building.

The continued development of new sources has been followed[195] by the design of new fixtures, but more and more there are indications of a departure from stereotyped ideas for both gas and electricity.

Gas.—In the case of gas, glassware has been developed[196] for small units to harmonize with that used for large units when both sizes are employed in the same location. Wall-bracket, boudoir, and semi-indirect portable and table lamps have been brought out in a wide variety of finishes and materials. Semi-indirect fixtures, with a large bowl hiding all of the Bunsen parts, are being increasingly used in place of the large and massive gas fixtures with separate arms.

The portable reading lamps having a 6-ft. standard and

191 *Ltg. Jour.*, Jan., 1915, p. 9.
192 *Elec. Record,* Sept., 1915, p. 52.
193 *Gas Age,* Feb. 15, 1916, p. 197.
194 *Ibid.*, Apr. 1, 1916, p. 430.
Am. Gas Lt. Jour., Jan. 24, 1916, p. 61.
195 *Elec. Rev. and W. E.*, Mar. 4, 1916, p. 433.
196 *Gas Age,* Mar. 1, 1916, p. 300.

large silk or other cloth shades have been adapted[197] for use with gas mantles. By employing the newest type of burner and a special protecting cylinder of mica it has been found possible to confine the opening in the top of the shade to a diameter of only 5 in. No glassware is required or used.

In order to meet the varying conditions necessitated by the three types of lighting, direct, indirect and semi-indirect, convertible fixtures are available[198] which with very little change in the parts enable the manufacturer to supply any type desired. Such fixtures which have been more or less general in electric lighting are now being made for use with gas and acetylene.

In order to encourage more modern gas-lighting displays in the illumination of fixture show-rooms, a committee on the subject of lighting fixtures was appointed[199] by the Pennsylvania Gas Association.

Table Lamps.—A modification[200] of an idea developed some years ago in which an upturned diffusing bowl is used to hide the bulb of a table lamp, involves the use of a second and larger bowl below with arrangements for controlling separately the lamps in each bowl.

By using heat intercepting, non-conducting mica cylinders designed for ample ventilation, it has been found possible[201] to use silk shades on gas table lamps. Mica flour is used to frost over the outer surface of the mica thus concealing the mantle and diffusing the light.

In general there is a growing appreciation[202] that, by the use of properly chosen cloth for shades, the lighting fixtures of a room may be made to harmonize with their surroundings.

A novel use for a table lamp is found[203] in a combination lamp and phonograph. The base of the lamp serves to hold the disc-record, turntable, electric motor, talking box, etc. The sounds produced are led up through the pedestal and released beneath the glass shade which throws them downward and outward.

Glassware.—Valuable data on the diffusing and absorbing

[197] *Gas Age*, Jan. 15, 1916, p. 107.
[198] *Acet. Jour.*, Apr., 1916, p. 405.
[199] *Gas Age*, May 1, 1916, p. 530.
[200] *Elec. Rev. and W. E.*
[201] *Gas Age*, Feb. 15, 1916, p. 235.
[202] *Elec. World*, Nov. 13, 1915, p. 1095.
[203] *Sci. Amer.*, Mar. 11, 1916, p. 277.

properties of the materials used in lighting glassware have been worked up and reported[204] to this society by the Committee on Glare. The delicate color treatment of decorative china duplicated[205] in glass is one of the developments in shades. The tendency to use denser glass for semi-indirect bowls and shades has grown to a considerable extent.

In England, one of the effects of the war has been to cut off[206] supplies of glassware ordinarily obtained from the continent. As a result the Research Committee of the Institute of Chemists of Great Britain has worked out and established the formulas of a number of important varieties of glass used in special optical and laboratory work. The question of standardizing the various kinds of glassware used for lighting purposes both as to constitution and quality has been discussed by the London Illuminating Engineering Society with the hope of being able to establish the best types and sizes of lamp bulbs, chimneys, globes, etc., in order to support the industry by bringing about economies in manufacture. The shutting off of the German supply[207] has led the English to undertake the production of heat resisting glass for use with high-pressure gas and other lamps in which considerable heat is evolved.

The fact that almost nine out of ten British factories are working on munitions of war[208] in one form or other has led to the development of globes and reflectors especially designed for such factory purposes. In Germany,[209] the change from the use of oil lamps to electric lighting necessitated by the exigencies of war, has stimulated the development of equipment for converting the old burners into modern electric fixtures.

For semi-indirect fixtures a novelty[210] in reflectors makes possible the use of any desired material such as silk, satin, cretonne, etc., of a pattern and color to match the decorations. This is accomplished by using two glass bowls one inside the other with the cloth placed between. The upper piece of glass is a pris-

[204] TRANS. I. E. S., May, 1916, p. 367.
[205] *Elec. Merch.*, May, 1916, p. 207.
[206] *Elec. Rev. and W. E.*, June 17, 1916, p. 1105.
[207] *Jour. of Gas Ltg.*, Apr. 4, 1916, p. 33.
[208] *Elec. Eng.* (London), Nov. 18, 1915, p. 465.
[209] *Elek. Anz.*, Dec. 12, 1915, p. 645.
[210] *Ltg. Jour.*, May, 1916, p. 107.

matic reflector and thus a large part of the light is efficiently reflected to the ceiling.

By arranging[211] plane mirror reflectors of definite dimensions and of certain angles in a conchoidal curve, with lamps about 18 in. apart at the focus of the curve, a complex system of direct and reflected light is obtained in a new fixture for show-window lighting.

A new style of lower-deck lighting fixture has been developed[212] for railway cars. The requirements were for a fixture which, when flush mounted along each lower deck rail, would amply illuminate both the reading plane and the ceiling without glare and without the use of additional fixtures.

For use in flood-lighting[213] a silvered-mirror reflector has been brought out, in which a special heat resisting backing is employed to protect the silver reflecting surface from tarnishing. The objectionable[214] bright spots, both on the side walls and directly above most wall-bracket and cove-lighting units, have been eliminated in a new form of shade designed to produce uniform illumination on the ceiling. The unit is placed in a wall box.

Fittings.—The soaring prices of metal fittings abroad[215] has led to the development of semi-indirect fixtures in which the glass bowl is supported in a holder made of wood. Very decorative effects have been obtained. A simple diffuser has been brought out[216] which can be snapped on to the socket and will prevent excessive glare from a clear bulb incandescent lamp in places where a shade is not feasible. For use in hotels[217] where it is desired to produce extra concentrated lighting as in sample rooms, a removable lamp bracket has been devised. It is made to fit into receptacles of the disappearing type. A screwless support[218] for inverted gas-burner globes has been developed in England. In the suspending lip of the globe are made three notches or free-ways through which slip three pins on the inside

211 *Elec. Eng.* (London), June 8, 1916, p. 212.
212 *Rwy. Elec. Eng.*, Feb., 1916, p. 264.
213 *Elec. World*, Oct. 9, 1915, p. 825.
214 *Ltg. Jour.*, Apr., 1916, p. 75.
215 *Elec. Times* (London), Apr. 6, 1916, p. 253.
216 *Elec. World*, Mar. 18, 1916, p. 674.
217 *Pop. Mech.*, Mar., 1916, p. 441.
218 *Jour. of Gas Ltg.*, May 23, 1916, p. 398.

supporting ring of the burner. A new type of holder[219] for glass shades has its points of support on the inside instead of the outside of the glass. In this way threaded parts, screws, rivets and soldered joints are avoided. In order to permit[220] of their being easily found in the dark, switches of the pull-chain and push-button variety have been announced which after they have been exposed to daylight or artificial light remain sufficiently luminous to be easily seen when the light is excluded. A phosphorescent material is used for this purpose. The great increase[221] in the use of indirect fixtures has created a demand for a special switching arrangement which will give individual control at the fixtures without having to use key-sockets. A device of this kind has been developed for metal reflectors, the wires coming to a decorative knob at the bottom where they may be connected to a twist- or pull-chain switch.

Standards.—A special cast-iron traffic post[222] to mark the interception of streets and serve as a guide and protection to pedestrians, has been brought out. It is intended to have it surmounted either by a ruby or a white diffusing globe. To avoid[223] the duplication of steel poles on a street in Salt Lake City occupied by a trolley line, the novel expedient was adopted of enveloping the trolley poles with large size pressed-steel standards. said to be the largest of this kind ever constructed. These standards carry three lamps, the height to the light source of the lower two being 26.5 ft., the third lamp being 2 ft. higher. The growth[224] in civic interest in lighting expressed in "White-Way" and boulevard lighting has brought continuous development in ornamental street-lighting standards of the metal type.

PHOTOMETRY.

During the past year developments in photometry have been confined chiefly to the solution of the problem of measuring gas-filled electric lamps, on the one hand, and of obtaining a satisfactory "physical" photometer on the other hand, while the

[219] *Elec. World,* May 27, 1916, p. 1260.
[220] *Ltg. Jour.,* May, 1916, p. 108.
[221] *Elec. Rev. and W. E.,* June 3, 1916, p. 1046.
[222] *Elec. World,* July 8, 1916, p. 95.
[223] *Elec. World,* June 17, 1916, p. 1433.
[224] *Elec. World,* Apr. 15, 1916, p. 903.

problem of the measurement of lamps differing in color has not been neglected.

Methods.—A method of photometry has been proposed[225] which is based on the sensitivity of the peripheral retina to brightness contrast, especially to the induction of black by a white screen.

Instruments and Auxiliaries.—The use of the integrating sphere is growing rapidly[226] as it seems to be the best means at present available for measuring the new types of gas-filled tungsten units. At the Bureau of Standards an 88-in. sphere has been constructed using reinforced concrete and was described at the midwinter convention. Tests were reported at the same time[227] on the cubical box as a substitute for the sphere, the results corroborating those of earlier investigators. Equations and experimental data have been given[228] on three types of variable neutral tint absorbing screens for use in photometry, the opaque line grating, the perforated opaque plate and the parallel wire grating. While not intended to take the place of arbitrary calibrations, the curves obtained show what may be expected in the use of such screens.

An improved form of physical photometer[229] has been described consisting of a sensitive thermopile in conjunction with an absorbing medium whose transmission is a copy of the spectral luminosity curve of the average eye. The construction and composition of the latter involves the principal improvement over previous efforts in this direction. Experiments have also been conducted to determine the thickness of the water cell[230] to be used with the above combination to cut out all the infra-red radiation. A layer of water 4 cm. thick is recommended to be used with a 1 cm. layer of luminosity solution.

Photo-Electric Cells.—The use of alkali photo-electric cells in stellar photometry has led to an improved type which has the required sensitiveness.[231] In the experiments carried out to find the most satisfactory type and conditions it was found that the

[225] *Jour. of Exp. Psychology*, Feb., 1916, p. 1.
[226] TRANS. I. E. S., May 1, 1916, p. 457.
[227] *Ibid.*, Mar. 20, 1916, p. 142.
[228] *Jour. Franklin Inst.*, Mar., 1916, p. 369.
[229] *Phys. Rev.*, Nov., 1915, p. 319.
[230] *Jour. Franklin Inst.*, Sept., 1915, p. 343.
[231] *Phys. Rev.*, Jan., 1916, p. 62.

best results were obtained with rubidium in an atmosphere of neon, tests having been made also on sodium, potassium and caesium, and with hydrogen and helium. Measurements on the cells finally adopted indicated accurate proportionality between the current and the luminous intensity.[232] The effective sensibility has been increased five- or six-fold over that previously obtained and it is claimed that a probable error of ± 0.005 magnitude may be easily obtained for stars of about 3.5 magnitude. As the result of further experimentation an explanation has been offered for the cases where a non-rectilinear relationship has been found to exist between the current of an alkali photo-electric cell and the illumination. The work indicated that the cause is connected with focusing effects resulting from the accumulation of charges on the walls of the cells.

A method for measuring illumination using alkali photo-electric cells has been tried out.[233] Two cells are put in series on a 40- to 40-volt circuit. An electronometer is connected to the poles of one of the cells which is illuminated by a source of constant candlepower. The other cell is then used for the measurements of illumination as required.

Flicker.—A flicker photometer has been devised[234] in which the ordinary cube of a Lummer-Brodhun photometer head is divided into two parts from one of which the light coming to one side of the photometer screen is reflected and through the other, light coming to the other side of the screen is transmitted. The cube is rocked back and forth so that the transmitted and reflected light appear alternately in the observation field.

Further work on the use of the flicker photometer for measuring light sources differing in color content has been done and was reported at the midwinter convention of the society.[235]

In consequence of another investigation[236] the following results have been reported. Different ratios of light to dark exposures require varying critical speeds. At high illuminations a maximum occurs for approximately equal light and dark intervals. At low illuminations using blue light the maximum at

[232] *Astrophys. Jour.*, Jan., 1916, p. 9.
[233] *Elek. u. Masch.*, Dec. 26, 1915, p. 626.
[234] *Zeit. f. Instr.*, Oct., 1915, p. 251.
[235] TRANS. *I. E. S.*, May, 1916, p. 331.
[236] *Phil. Mag.*, Apr., 1916, p. 290.

equal, light and dark exposures is absent. Instead the critical speed increases continuously as the ratio of light to dark interval is decreased. The relationship between illumination and critical speed is represented by the equation: Critical speed $= a$ log illumination $+ b$ where a and b are constants. The results indicate that the high sensibility of the flicker photometer is due to the very rapid increase in the critical frequency for disappearance of flicker on each side of the equality setting. Mechanical imperfections in the flicker photometer field seriously shift the equality point emphasizing the necessity for strictly substitution methods in this type of photometry.

Experiments on the flicker photometer frequency[237] show that, using a "white" standard, this factor varies radically with the spectral character of the measured light being greater at the ends of the spectrum than in the middle, with a minimum at about 0.575μ. The results confirm similar data obtained by a previous investigator.

Color.—An interesting inter-laboratory test of tungsten lamps at various voltages and of blue glasses of varying degrees of blue color was carried out[238] at the request of the Bureau of Standards. The results were reported at the midwinter convention.

Standards.—Researches on the effect of atmospheric conditions on the light from the hefner lamp have been made[239] and reported to the International Commission on Illumination. Experiments were carried on at various elevations ranging from 400 m. (1,312 ft.) below sea level and nearly 800 on the barometer to 3,450 m. (11,319 ft.) above sea level and with the barometer reading about 500 mm. of mercury. However, the results emphasized the necessity of confirmation by an investigation carried out in one locality. The formula based on the researches is as follows:

$y = 1.049 - 0.0062x - 0.033\ (x' - 0.75) + 0.00011\ (b - 760)$ in which y is the illuminating power of the hefner lamp; x is the volume expressed in liters, which the aqueous vapor associated with 1 cm. of dry air free from CO_2 would have at the same temperature and same pressure; x' is the CO_2

[237] *Jour. Franklin Inst.*, June, 1916, p. 853.
[238] TRANS. *I. E. S.*, Mar. 20, 1916, p. 164.
[239] *Elec.* (London), Nov. 19, 1915, p. 227.

contained in the air expressed in the same manner and b is the atmospheric pressure.

In view of the present knowledge regarding the properties of tungsten it has been suggested, as stated under the caption "Incandescent Lamps" that a standard lamp can now be constructed according to specifications. Thus it is claimed that a 10 candlepower unit lamp consuming 1 watt per candle may be designed using a filament 107 mm. in length and 0.054 mm. in diameter in the form of a single loop with a single support. At 17.5 volts the current should be 0.57 ampere.

Computations.—Measurements made on incandescent filament lamps having widely different arrangements of the filament in the bulb, indicate[240] that the mean spherical candlepower can be computed from readings of the mean intensity at angles of 54° and 126° from the lamp axis, thus obviating the large number of measurements ordinarily required or the use of a sphere or other integrating device. Tests showed that the difference between the mean spherical candlepower as measured and computed in this way, and in the ordinary way was in all cases less than ± 3 per cent. A simplification[241] of Kennelly's method for determining the mean spherical candlepower has also been worked out.

PHOTOGRAPHY.

Illuminants.—In England the use of gas lighting for photographic work has not been appreciated[242] although the subject is being agitated apparently as the result of successful work reported in this country. Three special types of flash lamps have been developed[243] for use where wild animals take their own portraits by flash light. An improvement in the use of artificial light for blue printing consists[244] in placing the sources inside a glass cylinder. This revolves and permits of a predetermined exposure of the print which is placed on the outside of the glass. The principle of the Ulbricht sphere has been applied[245] satisfactorily for the purpose of getting a strong diffuse light which will be as good for enlarging purposes as daylight.

240 *Elek. u. Masch.*, Sept. 26, 1915, p. 469.
241 *Elek. u. Masch.*, Oct. 10, 1915, p. 500.
242 *Jour. of Gas Ltg.*, Jan. 25, 1916, p. 189.
243 *Elec. Jour.*, Mar., 1916, p. 137.
244 *Elec. World*, June 3, 1916, p. 1319.
245 *Sci. Amer. Sup.*, June 3, 1916, p. 357.

Enlarging.—A novel method of enlarging photographs[246] dispenses with the use of a lens. This method consists in moving the negative to be enlarged past a narrow slit source of light and at the same time moving a sensitive plate under the negative at a speed equal to some constant multiple N of the speed of the plate. This positive is subsequently subjected to a similar action but with a motion now at right angles to the lines drawn out by the first operation.

Auxiliaries.—Data have been published[247] on the absorption spectra of a series of the aniline colors to be used in the making of color filters limited in their transmission to a chosen region of the spectrum. A method has been described[248] for making a spectrophotographic filter which will give results similar to those which would be obtained if one had a plate with an emulsion of uniform sensibility throughout its chief range of sensitiveness and an illuminant emitting equal amounts of energy of all wave-lengths to which the emulsion is chiefly sensitive.

For use in motion-picture photography[249] a portable lighting plant has been developed. It is equipped with apparatus for running wires and a 12-in. navy searchlight of the projector type.

PHYSICS.

Filaments and Flames.—An extended study[250] of osmium when made into filaments and mounted in exhausted bulbs has provided data on the relation between voltage, wattage, candlepower and current of such lamps. Osmium as a luminous radiator was found to be highly selective and its emissivity was determined as a function of both wave-length and temperature. For tungsten filaments measurements of the change in length with temperature indicate[251] the following formula for the thermal expansion between 1,200° K. and 2,700° K.:

$$\frac{L - L_{300}}{L_{300}} = 4.49 \times 10^{-6}\ (T - 300) + 2.4 \times 10^{-13}\,(T - 300)^3$$

Work has been done[252] on the determination of the conduction

[246] *Phys. Rev.*, June, 1916, p. 660.
[247] *Zeit. f. Wiss. Photg. etc.*, Oct., 1915, p. 133.
[248] *Astrophys. Jour.*, May, 1916, p. 302.
[249] *Pop. Sci. Mo.*, Dec., 1915, p. 788.
[250] *Phys. Rev.*, Apr., 1916, p. 451.
[251] *Jour. Franklin Inst.*, June, 1916, p. 857.
[252] *Phys. Rev.*, Apr., 1916, p. 431.

and convection losses in wires heated in the air. The results indicate that the energy loss per centimeter length within the range of temperature 900° K. to 1,700° K. is proportional to the absolute temperature T and that where the wires range in size over 0.2 to 0.7 mm. in diameter the value of the constant of proportionality is 0.0010.

Additional data have been obtained[253] on the distribution of energy in the visible spectrum of a cylindrical acetylene flame using certain types of burners and operating under defined conditions. In the region of the spectrum extending from the yellow to the violet the distribution of the flames examined appeared to be the same within the limits of observation but in the region of the spectrum extending from the red toward the long wavelengths, the emissivity was found to be greatly affected by variations in thickness of the layer of incandescent particles in the flame.

Light Sensitive Materials.—A study of the effect on copper oxide of exposure to light has shown[254] that there is an increase in conductivity similar to that in selenium and stibnite. It has been proved that the effect is not due to heat; and that the region of greatest sensibility lies in the ultra-violet near wave-length 0.280μ. Other experimental work on the action of light on copper oxide has been described.[255] In the case of selenium the effect of temperature on the resistance when exposed to light has been studied[256] and for the crystals examined it was found that the resistance both in the dark and when exposed to light is in general decreased with increase of temperature. The sensitiveness to light however does not vary greatly over a wide range of temperature.

Absorption and Reflection.—Additional data have been obtained and published[257] on the light-reflecting values of white and colored paints. The experimental arrangements consisted in placing a disk coated with the paint to be measured at the center of an integrating sphere and illuminating it with light shining through an opening at the top of the sphere. The interior

[253] *B. of S. Sci. Paper No. 279.*
[254] *Phys. Rev.*, Mar., 1916, p. 289.
[255] *Elec. Rev. and W. E.*, Aug. 5, 1916, p. 231.
[256] *Phys. Rev.*, May, 1916, p. 551.
[257] *Jour. Franklin Inst.*, Jan., 1916, p. 99.

of the latter received only such light as had at first been reflected from the disk. The effect of the vehicle on the coefficient of reflection of white paints was studied as well as the effect of slight tints. The attention of this Society has been called[258] to the loss of light and brilliancy in optical instruments due to reflection and that this may be partly remedied by properly oxidizing the glass used in the lenses. Experiments have been carried out on the effect of temperature[259] upon the absorption spectrum of various kinds of colored glass. It was found that for red, orange, light amber, lemon yellow and canary glass, the absorption increases with increase of temperature between 180° C. and 430° C., the effect being greatest for the longer wave-lengths.

Constants.—Work is still being done[260] on the mechanical equivalents of light. A value at the wave-length of greatest visibility (taken as $\lambda = 0.55\mu$) has been worked out using data obtained on the candlepower of a black-body radiator at various temperatures and is given as 760 lumens per watt. The mechanical equivalent of the lumen, taking 0.00 to 0.65μ as the wave-length limits of the visible spectrum has been experimentally determined[261] using a tantalum lamp. The result given was 4.5 or 5 ergs per second. Additional work on the constants of radiation of the black body to standard radiator has been reported. Three values have been given for the constant C_2 of the Wien equation, namely, 14,350 micron degrees,[262] 14,268 and 14,399;[263] for the constant Sigma of the Stefan-Boltzmann Law, 5.7×10^{-12} watt cm.$^{-2}$ deg.$^{-4}$.[264] Experiments on tantalum and graphite have indicated[265] for tantalum a value of 4.2 for the exponent in the integral radiation law $E = \delta T^{4.2}$ where E is the total energy emitted at a temperature T and δ is a constant. From the data on graphite it was concluded that its emissive power was constant and closely that of the black body.

Temperature.—On April 1, 1916, the German Reichsanstalt[266]

[258] TRANS. *I. E. S.*, Mar. 20, 1916, p. 220.
[259] *Phys. Rev.*, Feb., 1916, p. 194.
[260] *Jour. Franklin Inst.*, Mar., 1916, p. 421.
[261] *C. R.*, Jan. 24, 1916, p. 170.
[262] *Phys. Rev.*, June, 1916, p. 693.
[263] *Ann. der Phys.*, Oct. 29, 1915, p. 429.
[264] *Phys. Rev.*, June, 1916, p. 693.
[265] *C. R.*, Feb. 21, 1916, p. 294.
[266] *Zeit. f. Instr.*, Jan., 1916, p. 20.

inaugurated the use of a newly defined temperature scale which according to the present status of thermometry, corresponds to the thermo-dynamic scale. Between 0° and 100° C. the new scale agrees with the international hydrogen scale within the limits of error, while for very high temperatures it agrees with the radiometric scale, based on homogeneous black radiation but not with the gas thermometer. A true temperature scale for tungsten[267] and its emissivity has been worked out from experimental data on a hollow cylindrical tungsten filament perforated with small holes and mounted in a large bulb. A linear relation was found between emissive power and true temperature for the region 1,200° K. to 3,200° K. such that the emissive powers at the two limiting temperatures were respectively 0.467 and 0.406. Assuming the linear relationship to continue up to the melting point, the latter would be 3,630° K. Data have also been given[268] on the relation between lumens per watt of a tungsten lamp and the true temperature; the color temperature (as given by color match with a black body radiator); and the brightness temperature (as given by a brightness match against a black body) for wavelength 0.665μ.

PHYSIOLOGY.

A preliminary report has been made[269] of one of a series of investigations being carried out to determine the laws which govern the decay of a semi-circular after-image, variously produced, but always projected on a circular luminous field of its own diameter so as to fill one-half of this field.

An investigation has been made[270] of the sensitivity of different regions of the retina to light of various wave-lengths by the determination of the relative intensities at extinction of the various colors when received both on the fovea and at different distances from its center up to 10°. Eight observers were used. The results showed that in cases where the fovea is practically free from rods, the light just before it is extinguished, gives the sensation of color; while in cases where the fovea contains rods, so long as the stimulus is red, the color is distinguishable right down to extinction, but throughout the rest of the spectrum, the light loses

[267] *Phys. Rev.*, Apr., 1916, p. 497.
[268] *Jour. Franklin Inst.*, Mar., 1916, p. 418.
[269] *Jour. Franklin Inst.*, Apr., 1916, p. 579.
[270] *Phil. Trans. Roy. Soc.*, Dec. 6, 1915, p. 91.

color a considerable time before it is extinguished. In the first case the ratio of the foveal to the para-foveal intensities for equal brightness is about 1.2 at long wave-lengths. It rises to as much as 27 at short wave-lengths whereas this ratio remains between 1 and 2 throughout the spectrum for an observer whose fovea contains rods.

Some work has been done and reported[271] on color preference, and as to whether such preference is affected by the character of the surrounding light. Fifteen observers were used and made their choice of preference, from the standpoint of color alone, of fifteen colored papers. The results show that in general the colors whose dominant hues lie near the ends of the visible spectrum are highest in the preference order.

In working with photometers, microscopes, telescopes, and other instruments, a strain is sometimes felt[272] from the use of one eye and to obviate this an eye protector has been devised consisting of two mussel-shaped dead-black discs carried on the eye piece of the instrument and arranged so that either can be applied to one eye leaving the other free. The retina of the shielded eye is fully shielded from both direct and reflected light so that the eye can rest without even the strain of holding its lid tightly closed.

The results of an extensive study of the effects of radiant energy on the eye have been published.[273] Among the important conclusions arrived at may be mentioned the following: "as regards the general thermic effects of energy upon the eye there is no chance of damage to the retina or the media of the eye under any practical conditions of use"; "from the standpoint of effects upon the eye the ultra-violet region may be divided into two sharply separated portions, one of which (on the short wave-length side) produces abiotic effects while the other does not . . . the line of partition between these two portions (being) at $305\mu\mu$" "it is well within the bounds to say that there is no commercial illuminant from which the least risk of abiotic radiation is incurred under the circumstances of practical use." " . . . the most ordinary care of providing illumination with which comfortable vision can be obtained is sufficient for complete

[271] *Amer. Jour. of Psy.*, Apr., 1916, p. 251.

[272] *Sci. Amer. Sup.*, May 27, 1916, p. 343.

[273] *Proc. Amer. Acad. of A. and S.*, July, 1916, p. 630.

security against all possible injury from radiation." It is further stated that "the chief usefulness of protective glasses lies . . . in their reducing the total amount of light to a point where it ceases to be psychologically disagreeable or to be inconveniently dazzling." Attention should be called to the very extensive bibliography included in the publication of the above work.

LEGISLATION.

Factories.—Some progress has been made in interesting the Departments of Labor of the states of Pennsylvania and New Jersey[274] in the Code of Factory Lighting presented to this Society a year ago.

Just before the last convention and too late for inclusion in last year's report, there was issued[275] in London by the Home Office the first report of the Departmental Committee on Lighting in Factories and Work Shops. This Committee held thirty-eight meetings. Over fifty witnesses were examined and visits were made to a large number of industrial concerns. The chief points of interest in the report as summarized before the British Illuminating Engineering Society are:

(1) The recommendation that there should be statutory provision:
   (*a*) requiring adequate and suitable lighting in general terms in every part of a factory and workshop and
   (*b*) giving power to the Secretary of State to make orders defining adequate and suitable illumination for factories and workshops and for any parts thereof or processes carried on therein.

(2) The recognition of the value of good illumination as desirable in the interest of the safety and general health of workers and as an important factor influencing the output and quality of work.

(3) The actual record of work done contained in the appendices comprising data and measurements obtained in many factories supplemented by the general impression of the observers; and the summary of the requirements as regards lighting in the chief European countries and the United States.

The third volume of the report consists[276] of a mass of observations taken in 54 factories selected for the purpose in various

[274] *Elec. World,* Apr. 22, 1916, p. 956.
[275] *Jour. of Gas Ltg.,* Sept. 7, 1915, p. 524.
Illum. Eng. (London), Dec., 1915, p. 487.
[276] *Electrician,* Dec. 24, 1915, p. 409.

parts of the country. These factories were concerned with textile engineering, the making-up of clothing, and certain miscellaneous industries. Considerable variations were found in both daylight and artificial light in various factories.

A novel departure in the issuance of a report of this character was the publication of a four page memorandum summarizing the chief points of interest and hence of great value and aid to the technical journals. In connection with the work of the committee a considerable number of tests were made[277] in a specially equipped experimental room at the National Physical Laboratory. This report aroused a great deal of interest not only abroad but also in this country.

Subsequently a committee known as the Health of Munition Workers Committee issued a number of memoranda[278] one of which referred to lighting but added little to the rules laid down in the report previously referred to.

Bureau of Illumination.—A bureau of illumination service under the Department of Public Works has been established[279] by the City Council of Milwaukee and an illuminating engineer has been retained. The bureau will have charge of drawing-up specifications, letting contracts, supervising the installation and maintaining the new lighting system described elsewhere in this report. It will include a division of illuminating egineering, and a photometric laboratory is to be established.

Head-lanterns.—A law has been passed[280] in California requiring headlights to be permanently dimmed on state or public highways. The law prescribes that the center rays must not strike the ground further than 75 ft. from the front of the automobile. By an order issued[281] by the Interstate Commerce Commission, railway locomotives in road service between sunset and sunrise must have lamps with beams powerful enough to enable the detection of a man-sized object 1,000 ft. or more ahead under normal weather conditions. Similar provisions apply to locomotives required to run backwards. For yard and terminal locomotives a 300-ft. limit is specified. The order is made applicable to all new

[277] *Jour. of Gas Ltg.*, Sept. 21, 1915, p. 643.

[278] *Electrician*, Apr. 7, 1916, p. 1.

[279] *Elec. Rev. and W. E.*, July 8, 1916, p. 58.

[280] *Sci. Amer.*, Mar. 25, 1916, p. 321.

[281] *Cleveland Plain Dealer*, June 15, 1916, p. 17.

steam locomotives put in service after October 1, 1916 and to others given general overhauling before that date. All engines now in service must be so equipped not later than 1920.

Signs.—That lighted signs and show windows may add materially to sidewalk and street illumination on business streets is recognized in an ordinance adopted[282] by the city commissioners of Joplin, Mo., which provides that illuminated signs must be lighted from 5 to 10 o'clock every evening. On the basis of the claim that to the public the acceptability of electric signs lies in their usefulness in lighting the streets as well as improving the night appearance of the city, a movement has been started in another city[283] to compel the owners of such signs to keep them lighted from dusk to 11 o'clock. It is asserted that an issuance of a permit is a contract between the merchant and the city entitling the community to the full benefit of such lighting. The Ordinance Court at Louisville, Ky.[284] has rendered a decision upholding the validity of a city ordinance which required that the electric signs over a sidewalk must be kept illuminated from dusk until 10 P. M.

Vessels.—The Steam Boat Inspection Service of the Department of Commerce has issued[285] regulations regarding auxiliary lights fed from an independent source of power on passenger vessels and a number of such vessels have been equipped with emergency lights using the emergency radio storage battery as a power supply. Emergency lights are placed in the main passageways and in those leading to staterooms; over the doors leading to the decks; and on the boat deck near the lifeboats and rafts.

ILLUMINATING ENGINEERING IN GENERAL.

Daylight Saving.—Consideration is again[286] being given to the principle of ensuring the utilization of a larger part of daylight in the summer months by putting forward the hands of time pieces for an hour during a period made compulsory by legislation. It has been pointed out by Punch[287] that Benjamin Franklin was the real originator of the "daylight saving" plan. He

[282] *Elec. Rev. and W. E.*, Mar. 4, 1916, p. 408.
[283] *Elec. World*, Jan. 29, 1916, p. 272.
[284] *Elec. Rev. and W. E.*, June 3, 1916, p. 1048.
[285] *Elec. Rev. and W. E.*, Apr. 8, 1916, p. 650.
[286] *Nature*, Apr. 27, 1916, p. 183.
[287] *Christian Science Monitor*, June 13, 1916.

recommended it in a letter to Le Journal, Paris in 1784. Although the question has been agitated for some time in England, action was first taken by Germany to go into effect from April 30th to October 1st. In the former country there has been marked objection to the scheme[288] on the part of scientific men and the scientific and technical press. Nevertheless it has been adopted[289] for the period from May 20th to September 30th. The question was raised in France[290] two years ago and a commissionaire was appointed to investigate the effect of the change. No action was then taken. Early this year the Senate Committee in France rejected[291] the proposal for daylight saving. As in England, however, the plan was subsequently adopted to be in effect from June 14th to October 1st. In Holland the plan was put into operation[292] May 1st apparently without any material disturbance. Italy fell into line June 3rd.[293] It has also been adopted by Denmark, Sweden, Norway,[294] Turkey, Switzerland and Spain.[295] It should be noted that the above plan is different from the one adopted in Cleveland and mentioned in last year's report[296] as the latter involved a permanent change.

Light Sources.—Patents are still being granted[297] for the production of light by the incandescence of rare earth compounds heated by some form of blast flame. Additional information[298] has been obtained on the firefly, the species examined inhabiting the West Indies. The insect carries a green light on either shoulder and a bright orange light beneath the abdomen. If held in the hand while glowing, it gives out a perceptible warmth. The brighter light is only shown in flight and hence is hard to measure. A rough determination gave 0.004 candlepower. Other experimental work[299] indicates a confirmation of Dubois's work showing that there are two substances involved in the light pro-

[288] *Nature*, May 18, 1916, p. 250.
[289] *Ibid.*, May 11, 1916, p. 222.
[290] *Ibid.*, May 4, 1916, p. 209.
[291] *Electrician*, June 2, 1916, p. 274.
[292] *Jour. of Gas Ltg.*, May 23, 1916, p. 397.
[293] *Sci. Amer. Sup.*, July 8, 1916, p. 19.
[294] *Sci. Amer. Sup.*, July 8, 1916, p. 19.
[295] *Jour. of Gas Ltg.*, May 2, 1916, pp. 213 and 215.
[296] Progress Report, Trans. I. E. S., Oct., 1915, p. 559.
[297] *Jour. of Gas Ltg.*, Feb. 21, 1916, p. 264.
[298] *Nature*, Apr. 27, 1916, p. 180.
[299] *Science*, Aug. 11, 1916, p. 208.

duction in a firefly, a thermostabile substance, luciferin, which oxidizes with light production and a thermolabile enzyme, luciferase. In this connection reference might be made to a very extended survey[300] of the subject in an article on "The Production of Light by Animals."

The substitution of artificial light for natural light[301] is being pushed in all directions. It has been found practical to use the electric arc in testing dyes for fading. In an effort to familiarize the general public with some elementary facts, the Bureau of Standards has incorporated in a circular entitled "Measurements for the Household," data on the cost, amount and distribution of light as furnished by various types of gas and electric sources.[302]

The idea of using green color instead of white for the walls of operating rooms in hospitals has been extended[303] to towels and sheets around the area of the wound to be treated. By this means light is concentrated where needed and not diffused. Black has been tried but it has been found that this gives too much contrast. Ligatures do not stand out clearly against such a background. It is claimed that the relief to the eye by the use of green material around the wound is remarkable. Experience in this country has indicated that neutral gray is the best color for the background of the field of operation.

A novel use for the light sensitive characteristics of a selenium cell[304] is in the sorting of coffee beans. The latter are carried by a conveyor under the cell and the greater amount of light reflected by the light-hued beans produces a change in the cell which actuates a deflecting needle. This in turn operates a device that diverts these beans into a separate channel. The same principle may be applied to the sorting of grains, tobacco, and other products in which surface character or color is a distinguishing mark of quality.

Some years ago the so-called "electrical fountains" in which the streams of water were illuminated with various colors, were to be found in various places. There is evidence[305] of a revival

[300] *Jour. Franklin Inst.*, Nov., 1915, p. 513.

[301] *Sci. Amer.*, Nov. 27, 1916, p. 350.

[302] This publication may be obtained without cost on application to the Bureau of Standards, Washington, D. C.

[303] *Illum. Eng.* (London), Nov., 1915, p. 462.

[304] *Pop. Mech.*, May, 1916, p. 748.

[305] *Natl. Elec. Contractor*, Jan., 1916, p. 70.

of this form of illuminated fountains in smaller sizes in theatres and restaurants. Many attempts have been and are being made to improve the screen[306] on which the pictures are projected in cinematograph shows. A recently developed type is translucent and marked vertically by very fine ribs or prisms which help to prevent lateral foreshortening. It is claimed that the use of a translucent screen enables the camera to be placed on the side opposite to the spectators, thus practically eliminating the question of danger from fire.

Plants.—A report has been given[307] of the results of an extended series of experiments on the effect of light on plants. Among the conclusions arrived at are that the preception of light is located not in the leaf blade but in the leaf stock; that the apex of the stock behaves as a percipient region and is capable of inducing a motor response in the lower part; that the light stimulus brings about a permanent change by which the relationship of the tissues to one another as regards their tensions are modified.

Signs.—There has been an increase[308] in the use of sign boards made up with electric lamps for announcing news events. It has been found possible to flash three messages per minute and such a news service is to be put into operation in 25 cities. San Francisco has installed[309] street signs in the curbstones 6 or 8 ft. from the corners. A protected cast-iron box 40 in. long and 8 in. deep is set in the curb and equipped with a tubular light source. The outer side of the box is perforated with letters spelling the name of the street, the sign being visible day or night.

Standardizing Bureaus.—Only three hefner lamps were examined[310] by the Physikalische Technische Reichsanstalt during 1915. This was due not only to reduced home requirements but also to almost complete stoppage of orders from abroad. The embargo on the use of brass has interferred with the manufacture of these lamps. In addition to electric lamps durability tests were carried out on 33 incandescent spirit lamps and 1 inverted gas lamp. In the construction of spirit lamps other

[306] *Sci. Amer.*, Apr. 1, 1916, p. 347.
[307] *Nature*, Dec. 23, 1915, p. 468.
[308] *Elec. World*, Apr. 8, 1916.
[309] *Pop. Sci. Mo.*, Oct., 1915, p. 414.
[310] *Jour. of Gas Ltg.*, June 27, 1916, p. 690.

materials than brass and copper are used. The gasification of the spirit is started by an auxiliary flame which is subsequently automatically extinguished.

Societies.—Since the last convention a new association has been formed[311] to cover a field in which this society is deeply interested. It has been named "Optical Society of America." The purpose of the organization is given as the furtherance of the interests and to meet the needs of co-operation in applied optics. Those whom it is hoped to interest include "astronomers, designers of optical instruments, illuminating engineers, photographers, ophthalmologists, photometrists, colorists, petrologists, microscopists, and all investigators of optical problems.

Despite the conditions in Germany[312] the German Illuminating Engineering Society held its second convention, Oct. 23, 1915. A report by the Committee on the "Unit of Illuminating Power" referred to work being done on the unit of candlepower based on the radiation of a black body. The following agreement was reached and reported on by the Committee on Measuring Methods.

> A lamp may be rated either according to the mean spherical candlepower or mean lower hemispherical candlepower or the mean horizontal candlepower, but in every case it must be clearly stated which of the three candlepowers is meant. From a purely physical viewpoint the mean spherical candlepower is the most important, but for practical reasons it has so far been advisable to give up the other two candle-powers.

The Committee proposes that whenever the mean horizontal candlepower is given, the conversion factor should also be stated by which the mean spherical candlepower can be found. Two papers were given, one by Dr. Voege on recent improvements in objective photometry in which he comes to the conclusion that the photo-electric alkali cell has proved so far quite satisfactory and should be valuable in photometry. A second paper by Lummer was on aims and limitations of illuminating engineering and new methods for the determination of the temperature of bodies which follow the radiation laws and especially the sun. From experimental and theoretical consideration he

[311] *Science*, Jan. 28, 1916, p. 125.
[312] *Zeit. f. Bel.*, Nov., 1915, p. 121.
Elec. World, Mar. 25, 1916, p. 721.

concludes that 53 hefner candles per watt is the upper limit of economy for any source of light.

An effort is being made[313] to revive the old custom of placing candles in the windows of homes on Christmas eve.

The electrical industries[314] made the period from Nov. 29 to Dec. 4 the occasion for an electrical prosperity week and throughout the country extra lighting arrangements were a feature of the celebration.

LITERATURE.

The effect of the war is still seen in the scarcity of articles on illumination in the foreign technical press. Most of the older magazines have survived but some of the new ones have suspended publication. Among the books published should be mentioned:

"Color and Its Application" by M. Luckiesh.
New York, D. Van Nostrand Co., 1916.

"Light and Shade" by M. Luckiesh.
New York, D. Van Nostrand Co., 1916.

"The Rare Earth Industry" by S. J. Johnstone.
London, Crosby Lockwood & Son, 1915.

[313] *Elec. Rev. and W. E.*, Jan. 1, 1916, p. 24.
[314] *Elec. Rev. and W. E.*, Nov. 27, 1915, p. 981.

DISCUSSION.

L. C. PORTER: The Coast Guard of the government has been carrying on experiments with signal lamps, in which they have found that with a few dry batteries and a small tungsten lamp of 21 candlepower having high filament concentration, backed by a mangan mirror, signals can be transmitted at night over 50 or 60 miles, and plans are under way to equip all of the Coast Guard stations and ships with portable signal outfits of this type, so that practically all the stations will be able to communicate with each other up and down the coast, and with any passing ship.

Under the head of War, there is another development which is underway. Two years ago at Plattsburg experiments were tried in having the men charge into a row of search-lanterns, and it was found that the effect of the search-lanterns was so confusing

that the only way the charge could be made was for the men to hold hands, and naturally, when men are holding hands, they can't do much fighting, the search-lantern simply confusing them, so that they run in every direction. There are under construction trench lighting outfits which consist of a gasoline generator set which will be kept at a safe distance back of the fighting line and portable flood-lanterns operated from storage batteries. The flood-lanterns will be charged during the daytime and run up into the trenches at night, and if a charge is made, they will be put up above the trenches and trained on the enemy, which will make it very difficult, not only to charge but to fire.

Under the heading "Head-lanterns," I think that there is increasing legislation on the question of glare applicable to automobile head-lanterns, to locomotive head-lanterns, and also trolley car head-lanterns. With reference to automobile head-lanterns it may be of interest to know that the Society of Automobile Engineers, on their Standards Committee, have a subcommittee on the question of illumination, and they are working very hard, trying to standardize some method of lighting the road and at the same time eliminating the tremendous glare which at present prevails.

PRESTON S. MILLAR, of New York: I have been much impressed, as Mr. Cady has presented this report, by the fact that it is a real index to illuminating engineering progress evidencing the scope of the art in a very excellent fashion. It shows the advance of the year; it includes some comments on the more notable phases of the development of the art and in every way it is a very important contribution to our TRANSACTIONS. I think we should felicitate ourselves upon having such an active and comprehensive committee.

L. B. MARKS: Probably when this report was written the action taken by the State of Pennsylvania with reference to lighting legislation, had not been recorded. I see the statement, "Some progress has been made in interesting the Departments of Labor of the States of Pennsylvania and New Jersey in the Code of Factory Lighting presented to this Society a year ago." I think that statement should be amended to read that the State of Pennsylvania adopted the lighting code as prepared by the

Society on April 13 last, and that the law went into effect on June 1, 1916.

J. R. CRAVATH: We have on the subject of automobile head-lanterns, legislation in many towns, cities and states, but it is in a very chaotic state; nearly as bad as our locomotive head-lantern legislation in our various states. Now it seems to me that the men who are competent to guide legislation and public sentiment in this matter, are the men that we have in our Society. I think it is very decidedly the province of this Society to appoint some committee to take up this subject, to co-operate with the Automobile Engineers, if they are willing to be co-operated with, and study into the basic principles a little. I think if that is done, it will be a big step in the way of clearing up this chaotic condition we now have in connection with automobile head-lantern legislation, and may also show up some of the misdirected attempts now made to eliminate the glare evil on automobile head-lanterns.

OPTIC PROJECTION AS A PROBLEM IN ILLUMINATION.*

BY J. A. ORANGE.

Synopsis: This paper is a plea for the abandonment of the prevalent "point-source" treatment of projection (searchlights, transparency projectors) in favor of the rational "source-surface" method. A brief note on the searchlight and more complete discussions of the magic lantern and moving picture machine are presented in illustration. The bearing of lens-sizes and positions on the intensity and distribution of illumination at the screen is discussed. The screen itself is considered as a factor; the inadvisability of very high picture brightness and the possibilities of different sources with especial reference to the case of the tungsten filament lamp as against the carbon arc are discussed. The fundamental relations involved in illumination calculations are given.

The present day use of the term optic projection embraces searchlights, opaque projectors and transparency projectors. Under the first come floodlights and vehicle headlights in addition to regular searchlights. Opaque projectors are mostly adapted for handling postcards while transparency projectors deal with very various sizes from lantern slides which are about 10 cm. in diameter, movie theatre films 2.5 cm. in diameter, miniature movie films 8 mm. in diameter, down to microscope objects 0.5 mm. in diameter.

In a paper of this length one can only give a brief general discussion of the subject and an examination of certain applications. The treatment which is here given does not involve any new conceptions; it simply embodies a way of looking at the subject which apparently has not received the attention it deserves.

It is usual to consider the source of light as an approximation to a point. In what follows a source of light will be regarded as a surface having an intrinsic *brilliancy* depending upon the nature of the source. The extent of this surface may or may not be significant. Likewise the uniformity or otherwise of the surface. There is a cardinal principle of optics which is the key

* A paper presented at the tenth annual convention of the Illuminating Engineering Society, Philadelphia, Pa., Sept. 18-20, 1916.

to an easy understanding of projection. This is the principle of equal brightness which states that for any optical system the image is at best only as bright as the object. (Image is of course to be taken in the strict sense and is not to be confused with the manifestation produced by a screen.) Departures from equality of brightness occur only in consequence of the simple and obvious losses, namely absorption in glass, reflection at lens surfaces, etc., and incomplete reflection at mirror surfaces. This principle is so fundamental that it may be well to consider a few of its implications. First, the image seen in the use of a telescope is as bright as the actual object, barring the customary losses. Brightness is a quantity, the perception of which does not depend on distance; in examining a photographic negative or transparency by the aid of an opal window, it is immaterial what separation is used.[1] Next, in the case where a convex lens is casting a real image of a flame, say, an eye may be placed anywhere within the limits of the image and the lens surface will on inspection appear endowed with the brightness of the flame—again neglecting losses.

This difference is to be noted between ordinary material surfaces which are self-luminous and lens-openings, images, etc. The material surface may be inspected and will exhibit its brightness within a whole hemisphere of directions; the other surfaces admit of such inspection only within a strictly limited angular range of view-points. In fact so limited is this range in certain cases that the normal pupil of the eye is more than sufficient to cover it. The reconciling of physical and visual brightness is simply a matter of presupposing the use of a sufficiently small pupil; in any case the difficulty does not occur in connection with the study of projection.

The commonest cause of confusion in the study of projection is an unjustified assumption that light may be directed and controlled to any desired extent, irrespective of the character of the source, provided one has a "concentrated" source.

Surface brightness is a primitive concept admitting of direct perception so that it is practicable to use it intelligently in projection studies even where the user is not clear as to the reason for the invariable equality. Approximate values of the mean

[1] Cravath, J. R., "On Brightness," TRAN, I. E. S., p. 394, No. 5, vol. IX.

source brilliancy offered by the generally available projection sources are given in Table I.

TABLE I.—ROUGH VALUES OF BRILLIANCY ATTAINABLE WITH PROJECTION SOURCES.

(These are mean values within the working area of the source, not local values.)

	Candlepower per sq. in.	Candlepower per sq. mm.
Coal gas flame	3	0.004
Kerosene	9	0.012
Welsbach mantle	30	0.04
Acetylene	60	0.08
Plane spiral carbon filament	300	0.4
Vacuum tungsten filament	750	1.0
Nernst multiple glower	1,500	2.0
Lime-light	2,000	3.0
Gas-filled tungsten filament	2,000 to 24,000	3 to 40
Direct current carbon arc, soft cored	84,000	130

NOTES.—(1) Flame sources may be made to yield higher brilliancy (within about a twofold range) by taking advantage of their partial transparency, arranging a series of flames in line or using a concave spherical mirror.

(2) The range shown for gas-filled tungsten lamps is explained by the extremely different types which are available, from the 110-volt, 100-watt, giving 500 hours life, to the extremes of low voltage, heavy current lamps giving about 100 hours life.

Now in any actual case of projection the illumination at any point is subject to an obvious upper limit determined by the brilliancy of the source.

THE SEARCHLIGHT.

The searchlight, for example, may present an apparent area A of mirror towards the point in question, the source used has a brilliancy B and the "throw" is a distance x. The limiting illumination is then $\frac{A \cdot B}{x^2}$. In actual practice the limit is $\frac{A \cdot B}{x^2} \cdot k$ where k is the coefficient of reflection of the mirror, and this limiting value can always be reached for any point of view provided the source be sufficiently extended. Ordinarily there is a conical zone around the axis in which the limit is reached, that is, the whole mirror-opening presents a bright appearance. There is a second zone enveloping this such that the included view-

points see the mirror divided as it were, into white and black portions, the former exhibiting the source brilliancy—modified of course by the imperfect reflectivity. Outside this zone the mirror presents a perfectly dark appearance. The form of the conical zones is determined by the extent of the source and its relation to the focus, and the geometry of the mirror.[2]

The axial illumination being $\frac{A \cdot B}{x^2} \cdot k$, it follows that for a given diameter of mirror and for a fixed standard or minimum of illumination x^2 is proportional to B, $x \propto B^{1/2}$, that is, the range varies as the square root of the source-brilliancy. This relation holds only for an atmosphere in which no absorption occurs. The more misty the conditions, the less rapidly does the range vary with brilliancy. As an example, with a given size of mirror the range with a special tungsten source is about one half of that with the direct-current arc, assuming clear conditions; it is better than one half according as the atmosphere is hazy. (This is on a basis of tungsten lamp brilliancy about one quarter of the arc crater brilliancy.)

THE SCREEN PICTURE.

As a preliminary to discussion of the magic lantern and moving picture projector it is convenient to consider the question of the most suitable brightness of the picture shown on the screen.

This matter has never been standardized, although there does not seem to be any particular obstacle in the way of some agreement as to the most desirable brightness in the heaviest shadows of a picture, expressed as a function of the general room illumination. A combination of experiment with tests on theatres should settle this point, but the connection between such brightness and the intensity of illumination provided by the projector (measured in the natural way with slide or film out), is the source of much difficulty.

The relation rests on two factors, one the density of the slide or film and the other the nature of the screen. The former is very variable even in the regular photographic product while the various natural-color achievements may run into appalling densities. The most that can be done at this time is to agitate

[2] Benford, F. A., "The Parabolic Mirror," TRANS. I. E. S., p. 905, No. 9, vol. X.

for a standard density in the ordinary photographic records, there being little excuse for the extremes now run to. The dyed slides and films, moonlight and firelight effects, are not a disturbing feature because gloominess is there part of the effect sought. The natural color products require a higher order of illumination and should be specially provided for unless the exhibitor can contrive to negotiate them by recourse to such expedients as further darkening of the room, shortening of the throw and substitution of a highly selective screen.

The remaining consideration, screen character, is the one determining the relation between intensity of illumination and screen brightness, slide or film being absent.

Taking the white paint or muslin screens as a standard, the metallic or selective screens offer a factor[3] of from 1 to 7 as regards picture brightness, and where the design of the auditorium is appropriate they are very desirable. Taylor[4] speaks of satisfactory slide projection with ½ foot-candle (5½ meter-candles) in the clear parts, presumably with a muslin or white paint screen. H. P. Gage, in the discussion on the same paper, gives some figures which seem to suggest 2.5 to 6.0 foot-candles (27 to 65 meter-candles) for magic lanterns and 2.5 to 30 foot-candles (27 to 320 meter-candles) for moving pictures, again presumably on a matte white screen.

Regarding these figures it is interesting to note that a great many theatres operate successfully with less than 2.5 foot-candles (27 meter-candles) on a plain screen and that one of the best known theatres in the country is operating under conditions equivalent to considerably less than 10 foot-candles (107 meter-candles) on a plain screen.

The report of the Committee on Glare,[5] dealing with screens suggests a mean picture brightness of ½ lambert (? presumably *millilambert*) with a factor of 5 either way.

This mean value corresponds roughly with 2.5 foot-candles (27 meter-candles) on a white paint screen, measured with slide or film out.

[3] Committee on Glare, "Diffusing Media; Projection and Focusing Screens," TRANS. I. E. S., p. 92, No. 1, vol. XI.

[4] Taylor, J. B., "The Projecting Lantern," TRANS. I. E. S., p. 414, No. 3, vol. XI.

[5] Committee on Glare, "Diffusing Media; Projection and Focusing Screens," TRANS. I. E. S., p. 92, No. 1, vol. XI.

There is excellent reason for assigning an upper limit to the picture brightness in the case of moving pictures; this point will be referred to later (see page 18).

THE MAGIC LANTERN.

In its typical form the magic lantern is an instrument adapted to the projection of transparencies—slides—about 10 cm. in diameter. At different stages in its history it has been used successfully with such enormously different light sources as the kerosene flame, the lime-light and the carbon arc. Even when allowance has been made for the transparency of the old time slides and the smaller screens of early days, it still remains a wonder that such different sources should have served the purpose.

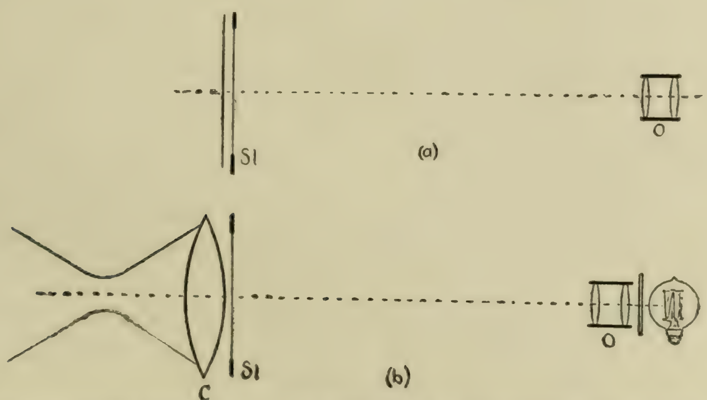


Fig. 1.—(*a*) Ideal magic lantern. (*b*) Back-testing a magic lantern which includes a condenser. *Sl* = slide. *C* = condenser. *O* = objective.

For the projection of the slide there is used an objective lens system somewhat similar to a camera lens. One can say immediately that the highest possible illumination is produced if one can contrive an extended background of source surface behind the slide (Fig. 1*a*). In this ideal case the illumination at the screen, the slide being absent, is $\frac{A \cdot B}{x^2} \cdot k$ where A is the apparent area of objective opening presented toward the particular screen-point considered, B is the brilliancy of the source, x is the throw and k is the transmission coefficient of the objective. (As

in the case of the searchlight the optical system presents an area endowed with the brightness of the source, neglecting objective losses, and the area, the brightness and the remoteness determine the illumination at the point in question.)

If it were not highly uneconomical and inconvenient in many ways this arrangement would be the natural form of magic lantern. In practice it is usual to use, not a background of source surface behind the slide but a background of lens-surface. Now, if there is an extended source-surface behind this lens—and at any distance, provided the source is indefinitely extended—then the lens-surface will appear as bright as the original source, neglecting reflection and absorption losses. If the lens is convex, there can be found one particular position for the source-surface at which a relatively small extent of source is completely sufficient. The result is a screen illumination $\frac{A \cdot B}{x^2} \cdot k_1, k_2$, where k_1 is the coefficient of transmission of the lens—again simply a matter of absorption, etc.—and k_2 is that of the objective.

The lens which serves in this way is known as a condenser. There is a simple way of demonstrating the possibilities of a condenser, *viz.*, by sending light backwards from the front of the objective, the latter being temporarily covered with a piece of ground glass. By holding a piece of paper behind the condenser one may explore the possible source positions; a circular patch of light is noticed which varies greatly in size with the distance from the condenser and the size of this patch indicates the maximum extent of source which is useful in the corresponding position, any further extension of source-surface being without effect (Fig. 1*b*). Any piece of glass which is free from flaws and is of a generally convex form will function as a condenser, but it is another matter to design a condenser which will facilitate the use of an extremely small extent of source.[6]

Standard practice involves the use of a pair of plano-convex lenses; in any particular case there is a limit to the degree of convexity which it is advisable to use since it will be found that the more extreme forms call for a greater extent of source. A

[6] On account of the serious aberrations, reference to the condenser as an image forming device is here purposely avoided.

much better result is obtainable if one can use non-spherical surfaces for the condenser, the sharpest curvature being near the axis. The difficulty of producing such surfaces commercially has restricted this development until very recently.

The limit of design on specially corrected condenser systems is really determined by the lens losses which increase more and more as the design (in effect, the number and convexity of the lenses) becomes extreme.

The magic lantern in this form is a relatively simple instrument. Rational design runs somewhat as follows: Knowing the size of slide and the average throw and screen size for which the outfit is intended, the focal length of the objective is fixed. Selecting some standard of illumination which the apparatus shall attain, making due allowance for the conditions under which it is likely to be used—as degree of general illumination and screen factor—there is next to be considered the means adapted to that end.

The expression for the illumination, $\frac{A\,B}{x^2}\,k$ involves area of objective opening and brilliancy of source, throw and coefficient of transmission (this latter covering both objective and condenser). The two latter quantities are known roughly so that one is left with a simple relation between objective opening and source brilliancy. The brilliancies of light sources are extremely different as has already been remarked and it follows that the size of the objective opening required will vary greatly. Attempts to use sources of very low brilliancy encounter the difficulty that extreme "aperture" in the objective is expensive and is subject to a fairly definite limit consistent with satisfactory definition in the projected picture. This applies particularly to oil, coal-gas and acetylene flames and the Welsbach lamp. There is a big gain in source brilliancy in going to the lime-light and Nernst lamp. The corresponding requirement in objective aperture is quite moderate and in fact it is not so much their optical character as it is general inconvenience which has limited the application of those sources.

The result is that the source which has been most commonly used until recently is the carbon arc. Here we have something

which far transcends even the lime-light and Nernst lamp in brilliancy and the size of objective opening needed is very small. In consequence of this the arc lantern as generally used is contrived a little differently from the instrument so far discussed.

A certain small aperture will suffice for the objective and with the best choice of plano-convex condensers a certain size of source is then required.

Now it follows from the existence of marked spherical and chromatic aberration in the condenser that one may with advantage use an objective which is larger than is really necessary but at the same time arranging so that each screen-point is served only by a small portion of the objective.[7] Perhaps this device is more readily understood from a numerical example. Suppose that on the basis of arc brilliancies it is concluded that 1 sq. cm. of objective opening is ample. If one were to provide an objective with that amount of opening and then add the most suitable form of plano-convex condenser it might be necessary to use an arc-crater 15 mm. in diameter. On the other hand it would be possible to use an objective 16 sq. cm. in area of which only 1 sq. cm. would be utilized by any particular screen-point; this might be attained with perhaps only 10 mm. arc-crater, using the same condenser arrangement. This alternative arrangement is the one corresponding to the rule which is given in books on projection, namely that the convergent beam coming from the condenser shall penetrate the objective so that no part of the beam shall be obstructed by the lens mounts, etc.

Another way of looking at magic lantern design for arc service is to consider that there are three ways of getting the desired results.

(1) Use a very small objective, an ordinary condenser and a large and expensive source (Fig. *2a*).

(2) Use the small objective, an expensive condenser and a small, cheap source (Fig. *2b*).

(3) Use an objective which has a gross aperture in excess of the "effective" aperture for any field-point, a cheap condenser and a small, cheap source (Fig. *2c*).

The choice is one that turns on relative costs of apparatus and

[7] Strictly one should say "each screen point considered with respect to a single spectral color."

rests with the maker; the third alternative is out of the question with sources of low brilliancy since difficulty and expense are encountered in attaining even the *effective* aperture they require, let alone anything larger.

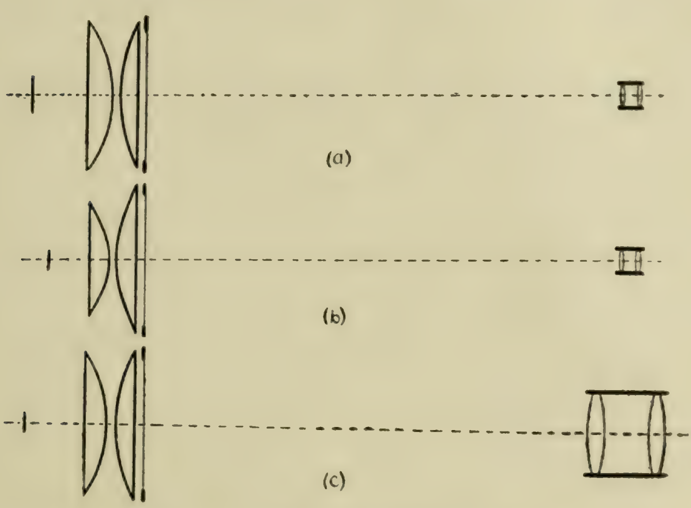


Fig. 2.—Alternative arc lantern arrangements.
(*a*) Objective very small, condenser cheap, source large.
(*b*) Objective very small, condenser corrected, source small.
(*c*) Objective large, condenser cheap, source small.

Recently the tendency has been to substitute a tungsten lamp for the arc and it is evident that this is sound practice. The tungsten lamp in its various special forms offers a brilliancy ranging from a value higher than that of the Nernst lamp up to a value exceeding one quarter of that of the direct current arc-crater. There is no difficulty in getting ample objective aperture for use in conjunction with such a source, but it ought to be remarked that erroneous conclusions may be drawn from tests in which an outfit designed for the arc is made to work with the incandescent lamp.

To sum up: the old illuminants (acetylene, mantle lamps, etc.) have such a low brilliancy that in order to get good results expensive optical apparatus is necessary and even then the possibilities are limited. Between these illuminants and the more recent there is a gain in brilliancy of from 100 to 1,000 fold.

This enormous gain renders it easy to provide optical equipment which will yield any results likely to be needed. Questions of convenience then come to the fore and there is no doubt that the tungsten lamp is in much the strongest position in the group (lime-light, Nernst lamp, tungsten lamp, carbon arc).

MOVING PICTURES.

The projection of moving pictures, while optically but an outgrowth of magic lantern work, is relatively complicated by the presence of peculiar features.

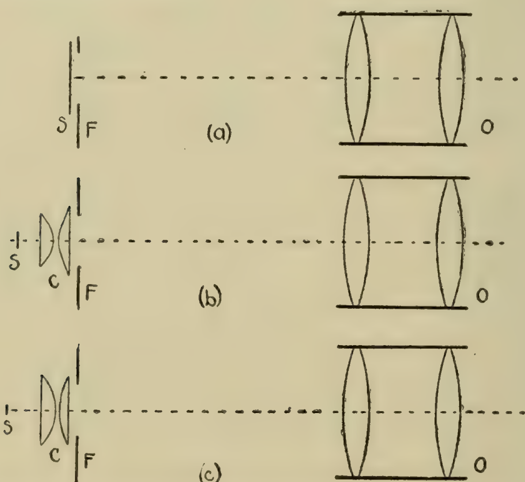


Fig. 3.—Movie systems. (*a*) Ideal. (*b*) Magic lantern type; adopted for theatre use. (*c*) The same adapted for amateur use.

The simplest mode of consideration is to omit all reference to the film movement and shutter action in the first instance, the problem being thus reduced to the projection of lantern slides 2.5 cm. in diameter as against 10 cm. One has, as before, an objective for the actual projection of the picture and just as in the case of the magic lantern previously discussed the limiting illumination at the screen is $\frac{A \cdot B}{x^2} \cdot k$ and the ideal means of attaining it would be an extended background of source surface behind the slide (Fig. 3*a*). This is as impracticable as in the case of the magic lantern proper and the logical thing to do is

to provide a condenser immediately behind the slide, followed in turn by a source surface. Even this miniature edition of the complete magic lantern is difficult to use except in amateur work. The reason is best seen from a numerical example.

A regular magic lantern might disclose the following particulars:

Slide diameter	10 cm.
Objective focal length	36 cm.
Effective objective aperture	4 cm.
Source size	1 cm.
Clearance, source to condenser	10 cm.

Now, if one wished to make a change from slide to film (*i. e.*, 10 cm. to 2.5) keeping throw, picture size and illumination the same, then the following would be about the scheme:

Slide diameter	2.5 cm.
Objective focal length	9 cm.
Effective objective aperture	4 cm.
Source size	1 cm.
Clearance, source to condenser	2.5 cm.

What one may term the factor of clearance, *i. e.*, the ratio of the two last terms, constitutes a serious difficulty because of the marked heating effect on the condenser and on the lamp bulb, if there is one. This difficulty becomes less marked in the cases where a smaller screen picture will suffice and in fact there are successful amateur outfits designed along these lines (Figs. 3*b* and 3*c*).

To avoid this trouble it is well to arrange theatre outfits so that instead of having a small condenser immediately behind the film one has a larger condenser further away. So long as the outlook through the film from all parts of the objective opening is faced by condenser surface, limiting illumination at the screen is possible, subject to the inevitable condenser losses (reflection, absorption and, in the case of Fresnel lenses, interruptions between rings) (Fig. 4*a*).

There are an indefinite number of possible condenser positions, the greater the distance from the film the greater being the diameter of condenser required to give limiting illumination over the screen. The single advantage of increased source clearance has to be set off against increased absorption and increased cost

as well as a slightly decreasing economy, *i. e.,* the more remote condenser positions require a slightly larger extent of source (if the *size* of the condenser but not its *form* be varied). For these reasons it is well to adopt a condenser position which is as near the film as is consistent with a satisfactory source clearance.

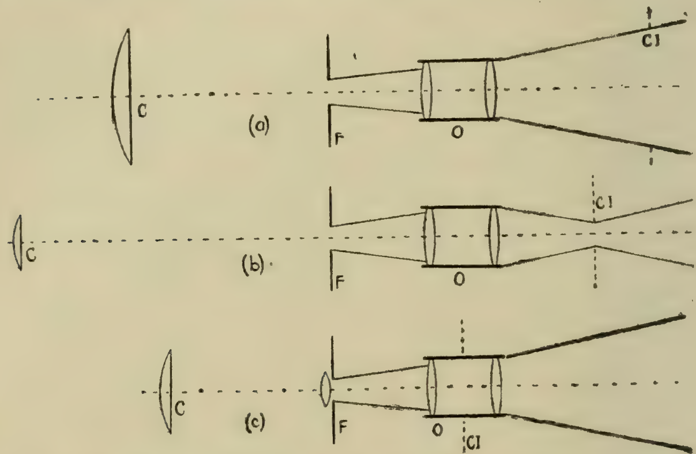


Fig. 4.—Movie systems. (*a*) Large, remote condenser for limiting illumination. (*b*) Small, remote condenser for low but even illumination. (*c*) Use of a field lens adjacent to the film. F = film. C = condenser. CI = image of condenser opening. Outlines of useful beam shown in each case (for shutter design).

The maximum ueful extent of condenser opening in any plane is defined by the locus of points from which it is possible to see through both aperture plate (the frame of the film) and objective simultaneously. The best position for the source and the maximum useful extent in that position are most easily determined by back-testing as described in the magic lantern section. This point should be noticed however: for some condenser arrangements back-testing will reveal two well defined spots in different planes, one being rectangular and the other circular. Naturally the smaller spot is the more economical source-position and either spot may be the smaller according to circumstances. The only kind of source which may be placed in correspondence with the rectangular spot, however, is one devoid of structure, such as a flame, because any source structure will be more or less clearly imaged in the film position and in turn on the screen. With a rough source it is essential to place it nearer to the condenser;

how much nearer is a question which depends on the degree of roughness of the source (coarseness and contrastiness of structure), the relative aperture of the objective and the degree of evenness desired in the screen illumination. In the case of a suitable tungsten filament and customary objective aperture it is sufficient in practice to adopt the sharpest circular spot as source position. (In short, while a perfectly smooth source may sometimes advantageously be placed conjugate with the film, a rough source must be placed more nearly conjugate with the objective opening.)

It is advisable to consider at this stage what effect is produced in the general case if one "stops down" or reduces the opening of a condenser so that it no longer satisfies the primary condition for limiting illumination over the screen.

In general the condenser opening is imaged some little distance ahead of the objective. (It may be readily found by using a slip of paper.)

The effect is this: from any viewpoint on the screen one sees as much of the objective opening at standard brightness as may be seen through the imaged condenser opening. Thus with some particular example of condenser opening it may happen that central points on the screen have a view of the objective opening quite unrestricted by this imaged opening, while peripheral points are not so fortunate. The result is a waning illumination as one moves towards the edge of the screen, a so-called vignetting action.

It is important to notice the various stages in the transition arising from a gradually shrinking condenser opening in the general case where the condenser is not very close to the film. First: with the condenser opening sufficiently large, limiting illumination is possible at all screen-points. Reduction of the opening is first effective in a slight darkening of the corners of the picture. The effect becomes more marked and eventually it is impossible to get limiting illumination even at the center of the screen. Carrying the reduction of the condenser opening further and further, the screen illumination steadily decreases but it becomes gradually more uniform. At a certain stage it becomes quite uniform and although further reduction of condenser opening leads to decreased illumination yet the distribution stays uni-

form. These changes are illustrated in Fig. 5 representing the distribution along the diagonal of the screen.

It may well be asked, of what interest is it to consider anything but the primary condition in which the condenser opening is large enough to secure limiting illumination all over the screen?

The extreme case of restricted condenser opening is very interesting because it is a condition advocated and practiced largely in the theatres to-day (Fig. 4*b*). That is,[8] a plano-convex condenser system of 4 in. (10 cm.) opening is often placed at 15-20 in. (38-50 cm.) from the film. The arrangement approximates to the stage *e* shown in Fig. 5, low but uniform illumination.

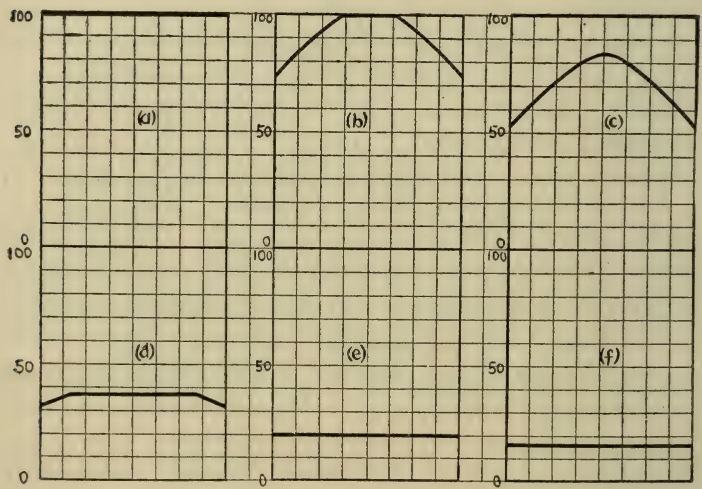


Fig. 5.—Distribution of illumination along screen diagonal as affected by relative opening of movie condenser; opening diminishes from *a* to *f* (abscissae represent position on diagonal, ordinates intensities).

There are advantages unconnected with illumination associated with this arrangement; these advantages will be related later and shown to be over-estimated (see p. 18).

The case of a slight restriction of condenser opening is of practical interest for the following reasons. The slight vignetting is not a *serious* disadvantage at least; some even go so far as to claim it as a positive improvement of the picture. There is quite an advantage in being able to use a smaller condenser size

[8] Richardson, F. H., "Motion Picture Handbook."

both on account of cost and, more important, the saving in thickness of glass which results in an improved source-clearance.

To summarize, the condenser for motion picture projection may conform with any of three conditions:

(1) Miniature magic lantern arrangement; condenser a little larger than the film and placed close behind it.

(2) Condenser at a distance from the film and of such a diameter as will lead to limiting illumination over the screen, or at any rate over the greater part of the screen.

(3) Condenser at a distance from the film and of such a *small* diameter as will give even or practically even illumination.

(There is a fourth arrangement which has had various supporters; this employs in addition to the condenser proper a small field-lens close to the film such that the condenser opening and objective opening are respectively conjugate, or in the relation of object and image. Lack of space forbids more detailed mention.) (Fig. 4*c*.)

As regards the *form* of condenser best suited to motion picture projectors, a few remarks may be of interest.

Amateur outfits using the magic lantern arrangement will give satisfaction with plano-convex condensers. The mode of operation resembles that of the arc lantern, that is, the effective objective aperture is less than the gross opening (Fig. 3*c*).

Corrected, *i. e.*, non-spherical condensers have greater possibilities with such outfits, but it is largely a question of cost. Such condensers would be very desirable if any attempt were made to use this arrangement in theatre work, in fact they would almost be essential (Fig. 3*b*).

Of the other condenser positions, it may be said that the non-spherical construction is always an advantage in spite of the fact that spherical aberration is not always a detriment (in limited amounts). There is always a saving in lens thickness and hence a diminished absorption and an improved source clearance when the corrected surfaces are used.

A peculiar form of condenser of the Fresnel type can be used for any position not immediately adjacent to the film.[9] In estimating the relative utility of such a condenser, it is necessary to set off the advantages of small thickness (hence low absorption

[9] A development due to Dr. H. P. Gage.

and good source-clearance) and cheapness against the disadvantages of considerable "discontinuity" and surface-scattering losses.

(A Fresnel lens necessarily has interruptions of aperture between the prismatic rings; in its aperture relations it is analogous to an ordinary condenser having black paper rings pasted on it.)

There is a possibility which has not been discussed, namely, the use of an extent of source which is smaller than that really called for by the optical train. This alternative, which involves using a smaller effective aperture of objective for any particular screen-point than would otherwise be used, cannot be adequately treated here. The resulting illumination is correspondingly low and there is no apparent advantage associated with this arrangement.

After this preliminary account of motion picture projection simplified by omission of all reference to moving parts, one is in a better position to review the actual requirements.

Standard practice involves the showing of sixteen pictures per second, each picture being held stationary in the proper position for about $^5/_6$ of the working period of $^1/_{16}$ second.[10]

It is necessary to interrupt the projection during the short intervals in which the film is moving, and further, since flicker is intolerable at 16 alternations per second, it is customary to interrupt the projection 32 or 48 times per second. (Thus for the latter case a cycle would be:

$1/6 \times 1/16$ sec., film moving, projection interrupted
$1/6 \times 1/16$ sec., film stationary, projection proceeding
$1/6 \times 1/16$ sec., film stationary, projection interrupted
$1/6 \times 1/16$ sec., film stationary, projection proceeding
$1/6 \times 1/16$ sec., film stationary, projection interrupted
$1/6 \times 1/16$ sec., film stationary, projection proceeding).

The necessary interruptions are affected by the rotation of a shutter, a circular disc with sector openings, at a suitable position in the path of the light. A 2-wing shutter revolving 16 times per second gives 32 interruptions and a 3-wing 48.

The only reason for using the 2-wing shutter is found where 60-cycle alternating current is used with an arc-source; were the 3-wing used, its frequency of 48 would give stroboscopic

[10] Gage, S. H. and H. P., "Optic Projection," 1914.

"beating" with the 60-cycle pulsations of the light intensity. Flicker is known to depend on intensity of illumination (or more strictly, on surface brightness) as well as frequency. Now, while the intensity used is unlikely to produce appreciable flicker at a frequency of 48, it should be remembered that there is the inherent 16 per second jumpiness of the picture details which are in motion.

This is an argument for restricting the brightness of the projected picture; it would seem that eye-strain may occur with two very different outfits, the alternating current arc giving relatively low illumination and a frequency of 32, and the very high power direct-current arc giving high illumination, an unobjectionable 48 frequency, and a 16 per second jumpiness which is prominent by virtue of the degree of illumination.

The best form of shutter device is a matter of considerable importance. The requirement is that the shutter be closed entirely throughout each interval of motion of the film and yet at the same time that the time-integral of the opening be as large as possible. It follows geometrically that it is desirable to have a shutter which is large compared with the section of the beam in which it operates. A number of alternatives are available:

I. The so-called inside shutter, operating near the film. Since this operates in a very constricted part of the beam, it may be made small and yet reasonably efficient. Apart from the general inconvenience of the position, there is the slight disadvantage that the different parts of the picture are not quite synchronous as regards the pulses of illumination.

II. The standard shutter used with the system which employs a 4-in. condenser opening at long range from the film. This system is characterized by a small image of the condenser opening a short distance ahead of the objective. The shutter is placed in this image-position and may then be made small. There is some slight advantage in the fact that the whole picture waxes and wanes in brightness together with this method. The one objection is the stopping effect of the condenser-image (so to speak), that is, there is a restriction of illumination which is more serious than the gain in shutter design.

III. The remaining case is that in which large condenser aperture is used and limiting illumination attained. The inside

shutter may be used if one cares to tolerate the inconvenience. Alternatively one would select as shutter position a plane immediately in front of the objective, such being the smallest section of the emergent beam.

The beam section is considerably larger than that utilized in the standard arrangement (II, above) and consequently the shutter should be scaled up in proportion, if efficiency is to be maintained.

(Some interesting variations are:

(*a*) A pair of shutters working in opposite directions through the beam; these can be made smaller than a single shutter for any given efficiency.

(*b*) A small one-wing shutter working at treble normal speed.)

Finally, there is the question of choice of light source for moving picture projection. Theatre work has depended almost entirely on the carbon arc. It might be thought that the superior brilliancy of the arc would constitute an invincible advantage, but when one examines the optical train used in this work it does seem that a source of lower brilliancy could be utilized, given appropriate arrangements. It is a fact that the majority of objectives in use have a much smaller aperture than might be provided and moreover the stop constituted by the condenser-image is a needless obstacle. Thus in any particular case the illumination at a screen-point, $\frac{A \cdot B}{x^2} \cdot k$, may be obtained just as readily by increasing A and decreasing B, that is, by increasing the effective aperture of the objective and decreasing the source-brilliancy.

(The contention that large aperture may be coupled with arc brilliancy and thus still higher screen illumination obtained is of no consequence. The main interest centers in such intensities as are giving commercial satisfaction to-day. The connection between intensity and flicker has also a bearing on this question.)

The extent to which objectives may be improved as regards aperture cannot well be discussed here. Suffice it to say that a certain well-known moving picture camera lens has 3-in. (7.5 cm.) focal length and F/1.9 aperture, which gives some indication of the possibilities.

The largest aperture projection objectives in regular use are about F.2.2. Such an aperture when used in conjunction with a special tungsten lamp and roughly limiting illumination conditions will give screen intensities of the order of those found in present commercial practice. It should be pointed out that the cost of the objective in most existing installations is relatively insignificant. An increased allowance in this respect is very desirable, in view of the importance of its function.

APPENDIX—MAGIC LANTERN AND MOVING PICTURE CALCULATIONS.

The limiting illumination at any screen point is

$$I = \frac{B\,.\,A}{x^2}\,.\,k \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1),$$

where B is the source brilliancy, A is the apparent opening of the objective relative to the point in question, x is the throw and k is the coefficient of transmission of the system. The apparent opening of the objective often varies in magnitude for different screen-points, particularly in the case of the magic lantern. This is analogous to the variation obtained with a window in a thick-walled building as one travels past, and is known as the vignetting action of the objective (see Fig. 6).

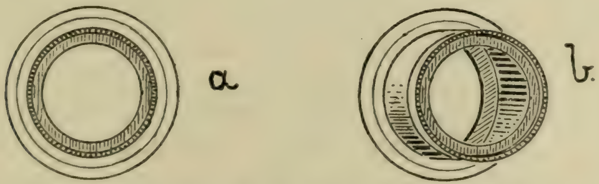


Fig. 6.—Aspect of magic lantern objective from center and side of screen showing variation in available aperture.

In general, limiting illumination is not attained, that is, the effective aperture of the objective for any particular screen-point (and in strictness, for any one spectral color) is less than the whole apparent opening or gross aperture and $I = \frac{a\,.\,B}{x^2}\,k$ where a is the *effective* objective aperture.

From the further relations:

$$\frac{x}{f} = m$$

$$\frac{f}{a} = n$$

where f is the focal length of the objective,

m is the linear magnification, and

n is the effective numerical aperture of objective we obtain:

$$I = \frac{Ba}{x^2}\,k = \frac{B}{m^2\ n^2}\,k \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2).$$

This implies that, other things being equal, magnification and effective numerical aperture should keep step if constant illumination is required. Hence the amateur's outfit giving a 3 to 6 ft. (1 to 2 meter) picture is well enough served by an objective working at small aperture while a theatre outfit giving a 12 to 20-ft. picture calls for proportionately extreme numerical aperture. This comparison is on a basis of equal film size; if the amateur's outfit uses miniature film then the magnification is necessarily higher, and with it the lens aperture requirement.

With regard to the common inquiry as to the projection of a fixed size of screen picture at a short throw and at a long, the answer is that different focal lengths of objective will be required and if these are of the same numerical aperture the illumination will be the same in the two cases. Since commercial objectives are of fixed diameter, in focal lengths exceeding a certain moderate value, it will be seen that with relatively long throws the possible illumination at constant picture size varies inversely as the square of the throw.

A third relation which is of interest in testing projectors may be derived as follows:

$$I = \frac{B\,.\,k}{m^2\ n^2}$$

$$\therefore I\,S = \frac{B\,.s.k}{n^2}$$

where S is the area of screen picture, where s is the aıea of film

or slide. But $I \times S$ is the number of lumens in the projection beam

$$\therefore\ L = \frac{B.s.k}{n^2} \qquad (3).$$

N. B.—In equation (1), I and x should involve the same unit of length—foot or meter as the case may be—and B and A should involve the same unit of area, square inch, square centimeter, or square foot. In equation (2) if I is stated in foot-candles, B should be stated in candles per square foot. In equation (3), B and s should involve the same unit of area.)

Rough values of the factors which together make up the constant k are as follows:

Coefficient of transmission of objectives	0.65
Coefficient of transmission of two-lens condenser	0.75
Coefficient of transmission of movie shutter	0.50

ADDITIONAL REFERENCES.

Eppenstein, (1) "Die Vergrössernden Projektionssystem," (2) "Die Beleuchtungssysteme," *Handbuch der Physik,* Winkelmann, 1906 ed., pp. 373-75.

Kruss, H., "Uber die Konstruktion von Kondensoren für Vergrösserungs und Projektions Apparate," *Z. für Instr. kunde,* 20.88, 1900.

McAllister, A. S., "Simplification of Illumination Calculations," TRANS. I. E. S., p. 587, No. 7, vol. X.

Neuhauss, R., "Lehrbuch der Projektion," 1901.

DISCUSSION.

HENRY PHELPS GAGE: Mr. Orange has made a rather complete study and analysis of the conditions found in moving picture and in ordinary lantern slide projection. I believe that this study was made from the standpoint of possible future development and throws a great deal of light on the possibility of what can be done and how to go at it. A number of years ago my father and I started to work out a complete illuminating engineering analysis of the conditions of optic projection, and we got to the point where we wished to inquire what the screen illumination should be. Right there we stopped the consideration of the illuminating engineering problem and made a few experiments, recorded the data and went no further. We did not

know, and there was no information to be had as to what the screen illumination should be. We made a few experiments, the results of which are referred to by Mr. Orange.

Mr. Orange presents the formula $\frac{A \cdot B}{x^2} \cdot k$ gives the screen brightness. This is a very useful formula, not taken so much mathematically as taking the common sense of the matter. That is, the screen brightness depends on the intrinsic brilliancy of the source, and also on the area of that part of the objective which is used; as for example, with the arc lamp. That one consideration is the greatest factor in getting a projection lantern in working condition that I know of. If you stand at the screen and use a suitable dark glass, and look directly at the lantern, observing how much of the objective is filled with image of the light source and how much is dark, you can find out what is the matter a lot of times. Suppose, for example, that one corner of the screen is dark; has a red shadow on it or something of that kind—by standing at that point and looking at the lantern, you can see what diaphragm in the system is to blame for the trouble. In studying microscopic projection, this method gave the clue to increasing the light on the screen, telling whether the aperture of the microscope objective was entirely filled with light. It was not filled with light, then a sub-stage condenser could be used which would fill the aperture with light, but such a condenser would not be useful unless a considerable increase of the aperture could be obtained, because in many cases we could not increase the illuminated area of the objective as much as 30 per cent., and the insertion of the sub-stage condenser reduces by about 30 per cent. the intrinsic brilliancy of the light source. In one instance, I was shown a projector using an incandescent lamp. At that time it did not work quite satisfactorily. By simply holding a dark glass up to my eyes, I could see that the image of the filament was way off to one side of the objective, and by a slight adjustment, I got that whole projector filled up with the filament image of this incandescent lamp and increased the screen illumination 30 per cent. over what it was before, showing what can be done by very simple means.

In taking up the theoretical consideration of lantern slide and moving picture apparatus, my father and I found that the ob-

jectives were very much larger than was theoretically necessary, but when applying that theoretical knowledge to practice, we found that in order to get a good picture on the screen it was a great deal easier to have a good big objective so that we could have the instrument a lot out of adjustment and still get a good picture. Now, regarding practical moving picture arrangements, the present moving picture outfits consist of a moving picture projector in which arc house lamp, and condenser slide over to one side and project lantern slides with the same arc. That is advantageous at present, because it takes quite a while to start an arc light, but it is not the most sensible scheme. It would be much better to have one apparatus for projecting moving pictures and a separate apparatus for projecting lantern slides. That will be the great advantage of the incandescent lamp. By simply changing a switch from one to the other, the lamp lights up instantly without any trouble, and will enable a successful design to be made in which the projection of moving pictures is entirely separate from the projection of lantern slides.

J. A. Orange: I would like to add a little to what Dr. Gage had to say about the combination of slide and film features in the moving picture machine. Certainly it does seem at the present time that it would be a great advantage to divorce the two features of the outfit except in those cases where the man who is showing is traveling around the country and desires portability above everything. Certainly for the stationary operators in the theatres, it is a much better proposition to use the stereopticon independently if you are using an incandescent source. In any case one has to use separate objectives for the two kinds of projection and the only thing that remains to be considered is the cost of the extra condenser and lantern (sheet-iron housing); whereas what is gained by having the two things separate is very considerable.

In the case of anything going wrong with the film outfit, you have the slides available to cover up the period during which readjustments are being made. With the arc that is not so because one cannot rely on getting it started, but with the incandescent lamp, turned on by the snap-switch the moment the slides are wanted, I do not see any reason why they should not be independent. Then you have freedom to design so as to give

the best service in both species of projection and not merely a best compromise.

The discussion of elliptical reflectors illustrates the difficulty of the treatment which starts with the flux given by the source and considers the successive fractions which survive at different stages in the progress through the system. A method which follows those lines is very apt to lead one into error, although it is not denied that it will yield the same results if it is done carefully enough, but I have seen a number of demonstrations of that kind which led to absurdities even in the hands of professed opticians.

The elliptical reflector is merely an alternative form of condenser, that is condensers in general fall into two families, the first involving only lenses and the second mirrors (with or without lenses in conjunction).

Any form of condenser has the sole function of economizing source, that is of enabling one to use a small source where otherwise a large one would have to be used to obtain the same effect.

The elliptical reflector has merit as a condenser though not so much as some of its advocates imagine, the reason being, as pointed out by Mr. Benford, that conclusions are based on the assumption of the use of a "point-source" which has no actual existence. The whole subject of condenser design has been very little studied as far as I can learn and the relative merits of simple lenses, non-spherical lenses, Fresnel lenses (one type of which is being developed by Dr. Gage) and mirror combinations are yet to be established.

I think that a system based on the use of the elliptical reflector might, if properly studied out, give some advantage of economy though not a very large one, but it has this peculiar difficulty, that you light source equipment—for instance arc-carbons and holders—is apt to get in the way of the beam you wish to use. This is particularly the case if one tries to keep the mirror small. On the other hand a large elliptical reflector of the requisite accuracy is expensive.

In short the reflector proposition seems to be at best only one of a number of closely competing devices.

With regard to the Strand Theatre and the conditions there, personally I think that the picture is quite as bright as is advis-

able from the viewpoint of eye-strain. The men who are in the business of projecting pictures, the managers and operators are apt to get the idea that the more light the better the outfit. They do not look at it from the spectators point of view, and I have seen bright screen pictures, pictures brighter than the Strand Theatre certainly, which were very tiring to the eyes. My own opinion, as I said before, is that this is tied up with the 16 per second picture frequency in combination with the brightness of the picture; for that reason I do not think it is very advisable to go beyond the picture brightness of the Strand Theatre.

REFLECTORS FOR GLASS BOWLS.*

BY J. L. STAIR AND J. A. HOEVELER.

Synopsis: In order that the art and science of illumination may be advanced to the greatest extent, without the need of sacrificing one to the other, it is recommended that the two elements should be separated. The need for this is illustrated by citing the many variable quantities that influence the lighting results and the great difficulty of securing glassware that is both artistic and meets the given lighting requirements. Auxiliary reflector equipment for use with ornamental glass bowls makes possible the attainment of this object. A reflector-diffuser is described, and photometric data pertaining thereto included, as well as test results of an actual installation. Maintenance of the equipment is discussed, and a novel means of eliminating the bluish hue of the glass bowl when used with the so-called blue-bulb daylight lamp.

INTRODUCTION.

The great increase in the variety and number of glass bowls on the market, and the extensive use of these bowls for interior illumination has put the illuminating engineer face to face with new difficulties. He is confronted by the problem of selecting glassware which must produce a desirable distribution of light for the given conditions, and which at the same time must have a contour and design which is correct artistically. Frequently one requisite must be sacrificed, at least partially, to secure the other, and usually it is the illumination, since but few people will accept glassware that is displeasing to them, regardless of how excellent the lighting results may be. On the other hand, the average person will select glassware which is pleasing to the eye even though it is very much deficient from the standpoint of best lighting practice. It will be found that much glassware which has artistic merit does not conform to best practice, and *vice versa*. Therefore, if by some means it is possible to make every glass bowl conform to best practice, those who are discriminating in the choice of lighting equipment, have at their disposal all of the many designs and types of glass bowls now available. This should make possible the accommodation of art and good illumination in practically every case. The purpose of

* A paper presented at the tenth annual convention of the Illuminating Engineering Society, Philadelphia, Pa., Sept. 18-20, 1916.

this paper is to describe means of accomplishing these results by the use of auxiliary reflectors within the glass bowls.

CHARACTER OF GLASSWARE AND OTHER CONDITIONS THAT INFLUENCE LIGHTING RESULTS.

In order to fully understand the need of using auxiliary reflectors for glass bowls it is only necessary to study the character of the innumerable types of glassware on the market and the conditions of the average installation. The diffusion and distribution of light from a glass bowl or any reflector, are dependent upon the type of glass, the general contour of the bowl and the position of the lamps within the bowl. Although the types of glassware available are of greatly diversified character, they may nevertheless be classified in several well defined groups. There is the roughed outside ground and etched glassware, with and without clear-cut designs; light density blown opal, glazed or etched; medium density opal, glazed or etched; heavy density opal, either pressed or blown, glazed, etched or iridescent.

With a given contour and lamp position each of these classes of glass bowls will give different distributions of light. This has been illustrated by previous tests conducted by Messrs. Rowe and Magdsick, in a paper entitled "Diffusing Glassware."[1] Likewise bowls of different contours but of the same type of glass as well as different lamp positions, show equally great differences in light distribution.

When one considers the number of variable quantities which affect the lighting results, the magnitude of the problem of securing art and correct illumination with a given piece of glassware becomes apparent. A certain contour of bowl may be most desirable, but with the type of glass chosen it may not be possible to get the proper distribution of light from the unit; or if the unit meets all lighting requirements it may be out of the question artistically. All of which goes to show that the two problems should be separated if we are to advance good lighting as far as it is within our power.

The fact that most of the above glasses transmit a large percentage of the light directly, is of particular significance since it indicates their brightness, when used under ordinary conditions,

[1] TRANS. I. E. S., vol. IX, No. 3, p. 220, 1914.

would be too high to be considered in accord with good practice. This would exclude probably 90 per cent. of the glassware offered to-day if we are to insist on getting the best lighting results. Hence, auxiliary equipment which will correct the shortcomings of this 90 per cent. will make it unnecessary to sacrifice lighting results to the artistic, which, unfortunately, is the prevalent procedure to-day. Furthermore, the use of such reflector equipment makes the contour and type of glass bowl independent of the lighting requirements. In other words, the reflectors may be chosen to give the proper lighting and may be installed in any glass bowl which will best suit the artistic. In fact, when used this way the glass bowl merely acts as an ornamental envelope or casing for the reflector equipment.

Since the advent of the gas-filled lamp, a characteristic of installations employing glass bowls equipped with these lamps and no auxiliary reflectors, is a sharply defined ring of illumination on the ceiling. This very disagreeable feature is well illustrated in Fig. 1. Reflectors in the bowl eliminate this condition, since they may be designed to give a more gradual and pleasing cut-off. The same fixture as shown in Fig. 1 is equipped with a reflector in Fig. 2. Since the time of exposure for each picture was the same, they indicate at least roughly, the reduction in brightness of the bowl brought about by the installation of the reflector. In order to indicate the exact transformation the brightness as read with a Macbeth portable illuminometer is indicated on each photograph. The size of lamp used is the 400-watt gas-filled, and is the size which is required for adequate lighting in this 20-ft. by 20-ft. room. As will be noted the cut-off on the ceiling in Fig. 2 is gradual and pleasing. The glass bowl of this fixture is 18 in. in diameter and of moderate density, having a slightly brown tone which produces a warm glow when illuminated. Although it is a very beautiful design appropriate for many interiors, the above test results indicate that it does not meet the requirements of best illumination results, without the auxiliary reflector, when used with lamps of the size required for adequately lighting the ordinary size room or bay.

Many glass bowls have beautifully etched designs, and some are artistically tinted. When these bowls are moderately illuminated, these decorations are strikingly revealed, whereas when

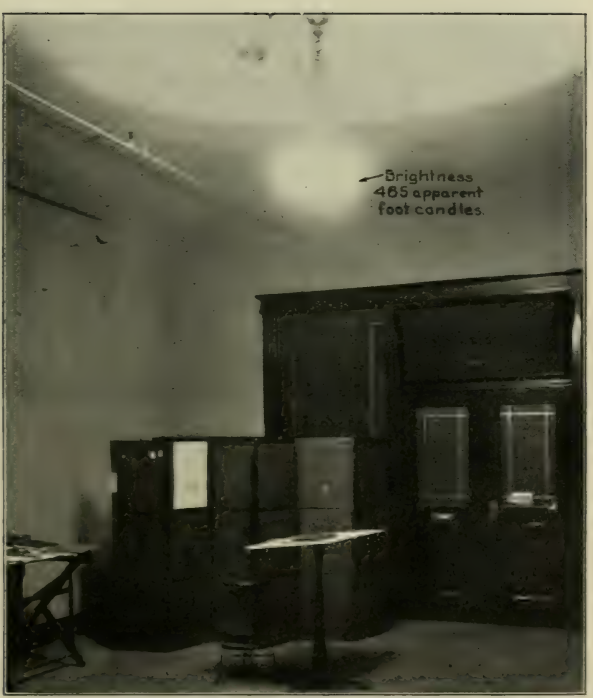


Fig. 1.—Installation of bowl without reflector.

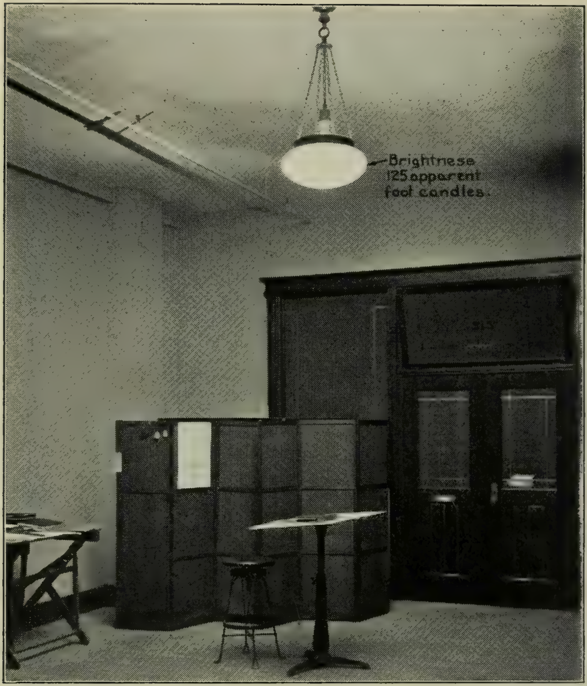


Fig. 2.—Installation of bowl with reflector.

Fig. 3B.—Reflector-diffuser for use in glass bowls.

intensely illuminated the decorations are partially if not completely obliterated. Therefore, artistic considerations also demand low brightness of bowl.

REFLECTOR AND DIFFUSER EQUIPMENT.

The prime reason for the great favor with which glass bowls are held for interior lighting, is the fact that they are luminous. Therefore, the first requirement of an auxiliary reflector is, that it provide a proper illumination of the glass bowl. The amount of illumination provided should be sufficiently low so that the surface brightness of the glass bowl will not exceed what is considered good practice. To accomplish this the reflector of necessity must be constructed at least partially of a translucent medium. Fig. 3A, Fig. 3B illustrate a reflector-diffuser device,

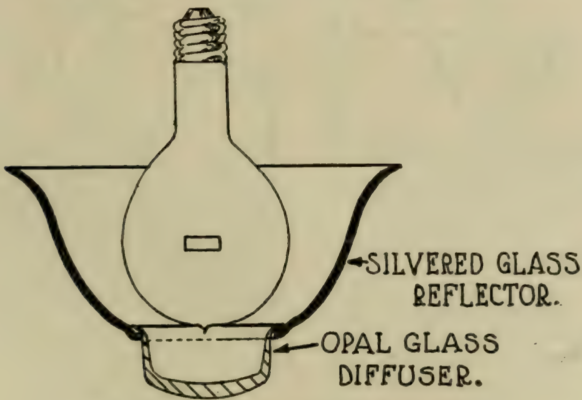


Fig. 3A.—Sectional drawing of reflector-diffuser.

designed to secure these results. It consists of a silvered glass reflector in the bottom opening of which rests an opal glass cup of variable thickness. The size and contour of the reflector and diffuser are so proportioned with respect to the size and position of the lamp as to reflect the major portion of the light flux upward, and to uniformly diffuse a very much lower percentage of the light flux downward for the illumination of the bowl. (The ratio of upward flux to downward flux is approximately in the ratio 10:1.) The diffuser is designed with walls of variable thickness in order to secure a uniform and pleasing distribution of light over the outer glass bowl.

Since the density of glass bowls is so variable, it may be desirable to have auxiliary reflectors which will give different proportions of transmitted light. This opaque reflector and opal glass diffuser combination provides a simple means of securing such variations. By merely changing the relative sizes of reflector and diffuser, the transmitted light may be varied at will. A similar flexibility with an all-translucent glass reflector would entail the difficulty of varying the density of the glass. Finally the inherent high reflection coefficient of silvered glass makes the reflector-diffuser combination a most efficient unit.

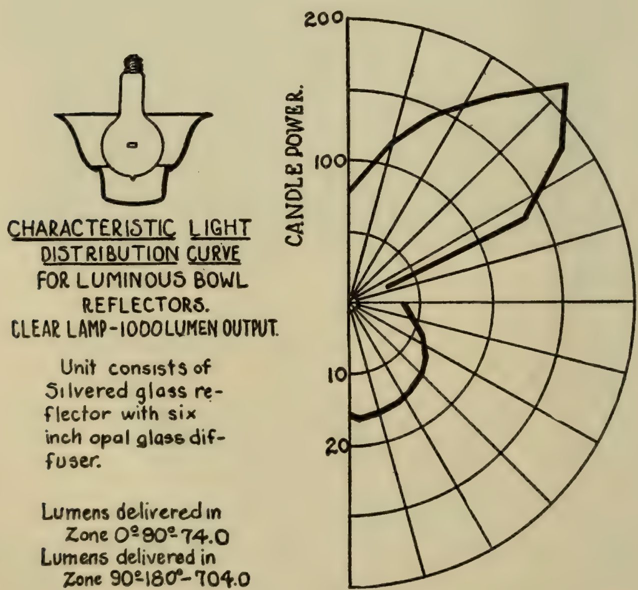


Fig. 4.—Light distribution from reflector-diffuser of Fig. 3.

The light distribution from a reflector-diffuser of this type is shown in Fig. 4. The lamp used when test was made, is the ordinary gas-filled tungsten, but the curve and data is computed on the basis of a lamp having an output of 1,000 lumens. Since a homologous series of reflectors may be designed for all sizes of lamps, this curve will be found serviceable for the entire series. Thus to learn what results are secured with the 500-watt lamp

in the respective size reflector of the series, the following formula may be used.

Candlepower of 500-watt unit = candlepower of 1,000 lumen unit × total lumens of 500-watt lamp ÷ 1,000.

From the curve and accompanying data, it is apparent that 70.4 per cent. of the light flux is delivered in the upper hemisphere and 7.4 per cent. in the lower hemisphere, the latter being available for illuminating the glass bowl. The transmitted light is low enough so that the surface brightness of a large percentage of glass bowls, when used with the sizes of lamps required under ordinary conditions, will be within the limits of correct practice, and will meet the artistic requirements previously mentioned.

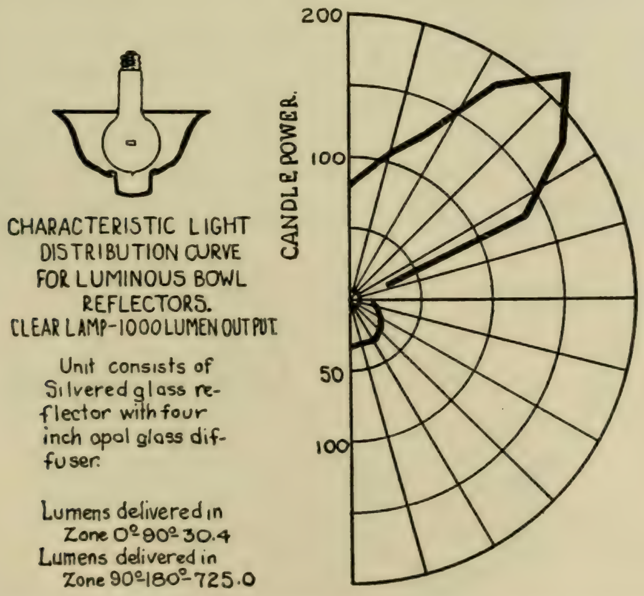


Fig. 5.—Light distribution of reflector-diffuser, wherein the size of diffuser relative to the reflector has been reduced.

To illustrate how this equipment lends itself to a change in the relative proportions of transmitted and reflected light, test data on a reflector equipped with a smaller diffuser is included (Fig. 5). In this case the transmitted light has been reduced to about one half. Frequently it is desired to employ glass bowls

of very light density, when the use of the smaller diffuser becomes essential.

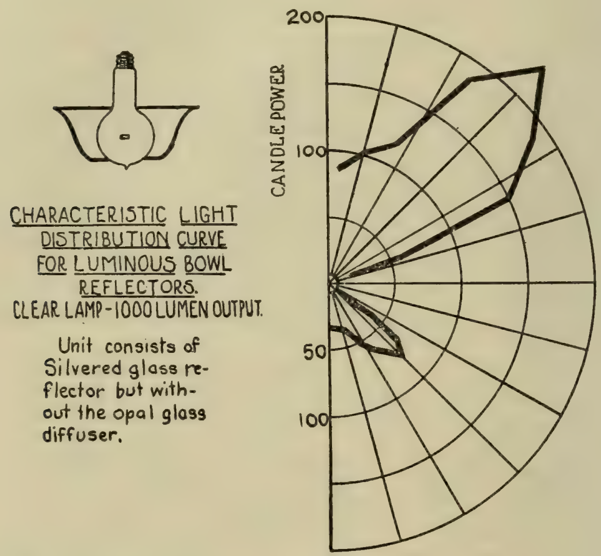


Fig. 6.—Light distribution form reflector without diffuser in place.

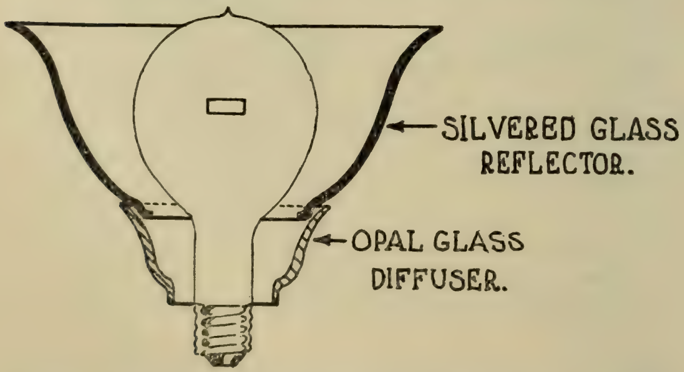


Fig.7—Reflector-diffuser combination for use when lamps are burned in the tip-top position.

Although the chief function of the diffuser is to redistribute and control the transmitted or direct component, like all opal glass it also acts as a reflector. In Fig. 6 a distribution curve on the reflector of Fig. 3, without the 6 in. diffuser in place, is

given. It will be noted that the candlepower values at the angles 135°-180° are lower than in Fig. 4 which shows that the diffuser is effective in reflecting flux into this zone.

As yet the gas-filled lamps except in the very small sizes (75 and 100-watt) are used almost exclusively in the tip-down position shown in Fig. 3. However, when it becomes desirable, the lamps may be used in the tip-up position in the manner shown in Fig. 7.

MAINTENANCE.

The continued success of any lighting system is dependent primarily upon the maintenance. After a lighting system is installed three factors tend to cause depreciation and result in a loss of illumination intensity. These are: (1) dust collection, (2) soiling of ceilings and walls, (3) aging of lamps. While the latter two conditions are important, they require attention only at relatively great intervals. Unfortunately the question of dust collection requires more constant attention if the lighting system is to be properly maintained. Data that has been presented to this society on the question of dust collection indicates that cleaning is required at intervals of 2 to 8 weeks, depending upon the local conditions.

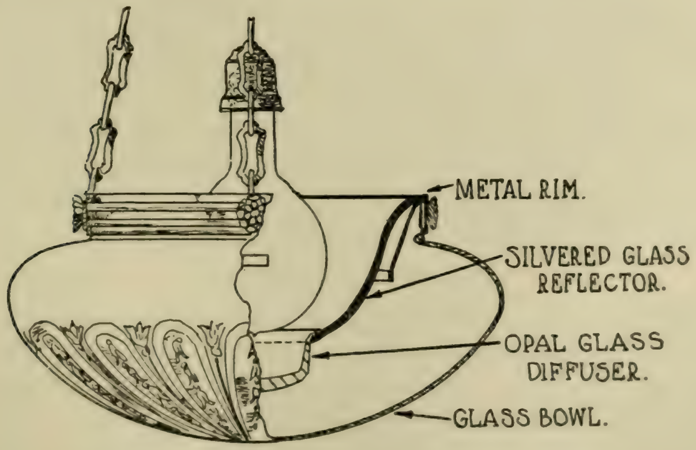


Fig. 8.—Reflector-diffuser installed in ornamental glass bowl.

The reflector-diffuser equipment simplifies the maintenance of fixtures. In Fig. 8 is illustrated in section, the glass bowl

of Figs. 1 and 2 equipped with a reflector-diffuser. The reflector fits snugly into the metal rim and prevents the deposit of dust on the interior of the bowl. The heavier particles of dirt accumulate in the diffuser which may readily be removed and wiped out. The reflector itself is cleaned by wiping with a dry cloth. There is ample space between the reflector and the lamp, making it unnecessary to remove either, and hence the task is greatly simplified. The dust accumulation on the exterior of the bowl of course does not interfere with the lighting efficiency, but should be wiped off for sanitary and other reasons. When the diameter of the glass bowl is greater than that of the reflector employed, the outfit may still be made dust-tight by employing an annular metal ring to fill up the space between the rim of the reflector and the glass bowl.

COLOR CUPS

A very interesting application of the reflector-diffuser is the use of color cups made of gelatine or glass, which may be nestled in the diffusers for the purpose of producing different color tones in the glass bowl. The use of these color cups does not materially change the quality of illumination in the room, because the transmitted light is such a small portion of the total illumination. The so-called blue-bulb daylight lamp, when used in glass bowls not equipped with these reflector-diffusers, gives the bowl a bluish cast, the psychological effect of which is unsatisfactory. By means of a suitable color cup the bowl may be given its original tint as when used with ordinary lamps, and at the same time we may get the benefits of the white light, since the major portion of the illumination comes from the ceiling.

MULTI-UNIT BOWLS.

Thus far the question of single-unit bowls only has been discussed. The multi-unit problem does not present any great difficulties, however. The use of diffuser equipment becomes unnecessary. A number of lamps properly proportioned in size to secure the correct balance between reflected light and transmitted light are installed in the bowl. In Fig. 9 is shown a reflector equipment designed for this purpose. The small pendent lamp provides the illumination of the glass bowl. Its size, of

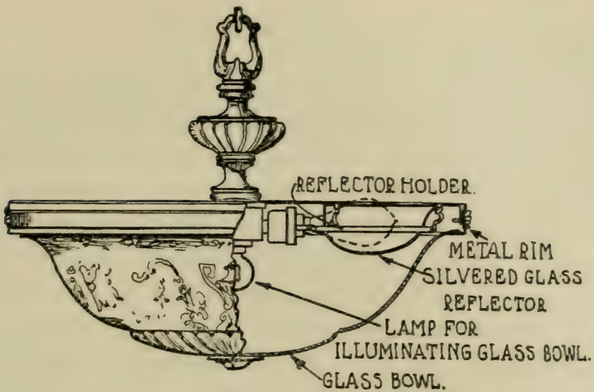


Fig. 9.—Multi-unit reflector equipment for glass bowls.

course, is dependent on the size and character of bowl, and must be selected in accordance therewith.

DISCUSSION.

W. R. MOULTON: It is interesting to note the method of light control offered in this paper. This is pleasing to the illuminating engineer, for he now has an additional tool with which to work. Greater variety can be had in his work and he can obtain results that are more pleasing to his client and satisfactory to himself.

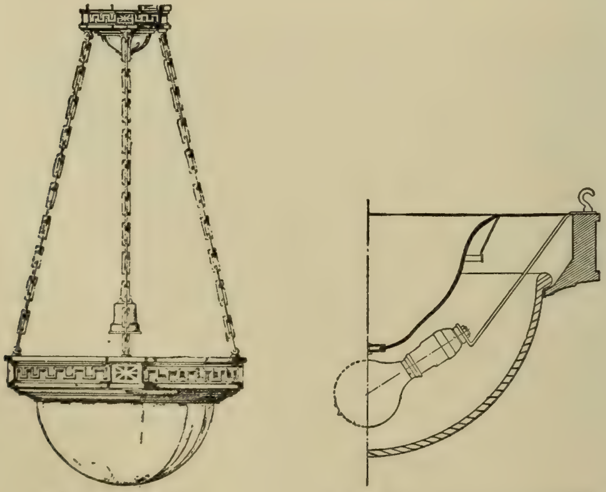
To offset some of the advantages of variety offered, we find complication of the lighting fixture, and therefore the possibility of variety must be balanced against the added complication to the best satisfaction of the engineer's client. It must be kept in mind that complication of fixture and its construction carries with it additional cost. Once more the illuminating engineer must weigh the advantages of the complicated system with their additional cost against simpler equipment.

From a practical standpoint, the control of light by means of special equipment, mentioned in this paper and also the previous paper, works out very well. They both have merit which appeals to the active fixture dealer and advantages which appeal to the consumer as well. The central station realizes that the consumer appreciates variations in the method with which he handles his light, as it enables him to do "stunts" in the lighting of his home. The consumer, who is at all interested in lighting, takes pride in

having something different from his neighbor and takes pleasure in showing it and talking about it.

NORMAN MACBETH: A short time ago we used another variation of the indirect fixture arrangement referred to by Mr. Stair that might be of interest. There is undoubtedly a considerable demand for semi-indirect lighting fixtures, but, as has been noted by other speakers at different times, there is considerable difficulty in securing glassware of the necessary density. Much of the glassware on the market results in an effect not any better than could be secured with almost any of the direct lighting fixtures, and having an order of contrast as great as 1,000 to 1.

In the fixture referred to, an opaque mirror reflector was used for the main lighting, and below this reflector was placed a socket with a single lamp. This was all surrounded by a hemisphere supported by the conventional band (see Fig. *A*). The



Sketch of fixture. Detail of fixture, showing the provision that was made to light the bowl.

Fig. A.

single lamp was a G-bulb, frosted, and this lamp could also be very conveniently colored and could as well be of sufficient size either to result in the intensity of the hemisphere being less, equal, or greater than the brightness of the ceiling. In this in-

stallation also two circuits were used to each fixture so that with one circuit on the fixture itself could be illuminated. The light from these fixtures, however, was not more than sufficient to result in a very low intensity throughout the room. The diffuser referred to by the authors results in a sufficiently low intensity on the enclosing glassware, but I was of the opinion that if this diffuser was colored, as may be desired at certain seasons of the year, the intensity would be altogether too low. The glass part of the fixture seen is a white glass and as such will take on any color it is desired. At the present time these fixtures are used with a deep amber dipped lamp.

I am aware that a somewhat similar arrangement has been in use where the lamps for the indirect lighting are on the horizontal and three or more lamps have been used with one lamp pendent into the hemisphere, but as far as I know, this arrangement using a single large unit for the indirect part of the fixture and a smaller lamp for the fixture itself is new.

J. R. Cravath: At first thought this plan of reducing bowl brightness appears rather complicated. One wonders why the same thing cannot be done in a much simpler way. Of course we all know it has been done in a simpler way, but the trouble has been to get glassware in sufficient variety to fill the bill, and this is one of the ways that has been evolved of getting the bowl brightness down to a value where it should be for hygienic reasons, and at the same time offering the customer the variety of artistic effects that he wants. The question of ceiling effect with the new concentrated filament lamp is one of the most troublesome things we have to deal with in connection with all semi-indirect lighting units, and that is a trouble that we have not only with opaque reflectors but with nearly all the translucent bowls. In that connection I would like to ask the authors whether the lamp position indicated on the various illustrations in the paper is the true lamp position that is used in practice. In my experience, the filament used has to be placed a little higher in order to get rid of those bad contrasty ceiling effects that were spoken of.

S. G. Hibben: In actual practice I have recently used a means of correcting this effect of bad ceiling shadows and chain shadows by dip-frosting the upper portion of the type-C lamp, in-

stead of the customary bowl frosting. That is a very simple method, yet it has been used but very seldom, and it does do away with any possible sharp cut-offs. If you have to use the lamp low in the bowl, that is one very practical solution of the problem of softening the edges of the ceiling shadows.

E. N. HYDE: Some years ago I believe there was considerable space in our TRANSACTIONS devoted to the results of combining the light of mercury tubes and incandescent lamps, because the color effect of the mercury tube alone was undesirable for want of the red ray. One installation was in the World Building. A Blondel-Saradake hemisphere enclosed a triangular-shaped mercury tube in series with which was burned a tungsten filament lamp, as I recall it. The mixture of the light flux from the two units was brought about mechanically by the diffusing and refracting prisms of the hemisphere and the resultant quality of light seemed to be a single flux having different characteristics from the flux of either one of the two components. I should like to ask the author of the paper whether there has been any attempt to modify the general lighting effects in a room by combining the light of colored lamps in the bottom of these bowls with the high intensity white light of the gas-filled lamp.

C. P. STEINMETZ: I believe it would be of interest, if it has not been done, to make photometric tests with the integrating sphere, of the complex fixture with light control and coloring devices to see what can be accomplished by this control and coloring of the light.

G. H. STICKNEY: Is it possible through such tests to account accurately for the absorption and surface reflections of a bowl?

C. P. STEINMETZ: Theoretically I see no reason why you should not get correct results when you desire to measure the total light flux in lumens. That is what I am interested in—what percentage of the total light flux, in lumens, issuing from the radiator has to be sacrificed to get the proper control in color.

J. L. STAIR: With reference to Mr. Macbeth's illustration, I might say that the amount of light that passes through the diffuser and is used in illuminating the glass bowl of the fixture is comparatively small. The use of the color cup in conjunction with the diffuser reduces the brightness of the bowl, but it has been found by experiment that it is necessary to increase the size of

the diffuser only slightly to obtain the desired brightness when the color cups are used.

Mr. Cravath asks whether or not the position of the lamp with respect to the reflector as it was used in the tests, corresponds to the position used in practice. The diagram in Fig. 3A shows the reflector diffuser with lamp in the proper position. This is the exact position for which the reflector was designed and is the same as used in practice.

No tests on the reflector diffuser have been made in the sphere such as Dr. Steinmetz speaks of. Tests of this character will give us very interesting and valuable information, and it may be that such tests will be conducted at some future time.

We have made few experiments with the deflector diffuser equipment in the colored lamp under the reflectors, except in cases of possibly a multiple unit equipment as illustrated in Fig. 9.

RECENT DEVELOPMENTS IN PRISMATIC GLASSWARE.*

BY HOWARD L. JENKINS AND GEO. W. ROOSA.

Synopsis: The concentrated filament lamps have been an important factor in the development of the prismatic reflector. A true point source would furnish ideal conditions for redirection of light from a properly designed reflector. The latest type "C" lamps approach this ideal source. This paper describes window lighting reflectors, reflector-refractors, panel reflectors and decorative prismatic units used to give proper illumination with concentrated filament lamps.

The developments in light sources are naturally followed by developments in lighting accessories. These developments are more pronounced in incandescent lamps than in any of the modern illuminants and consequently the reflectors used with them show the greatest improvement in design and efficiency. The most recent development in the incandescent lamp manufacture has given us the type "C" lamp, with its concentrated filament approaching a point source of light. This feature greatly facilitates the reflector designer's problem, as it gives him a practical point source to work with, rather than a theoretical source as is assumed when designing reflectors for other types of lamps.

This is particularly desirable for the design of prismatic reflectors where accuracy is expected. It is a well-known fact of science that a true prism located properly can redirect any light striking it, transmitting or reflecting it in any direction. On the basis of this principle, prismatic lighting glassware is designed. And for this reason the shape of prismatic reflectors are always determined by the type of lamp and the distribution desired.

It is true that the great brightness of the type "C" lamp has introduced a factor of glare which is objectionable and which has to be compensated for by a diffusing medium. This diffusion is accomplished in prismatic reflectors by the use of a highly developed etching process. This etching is applied on the inner surface of all reflectors that are designed for use with type "C" lamps and gives a very pleasing effect without seriously hamper-

* A paper presented at the tenth annual convention of the Illuminating Engineering Society, Philadelphia, Pa., Sept. 18-20, 1916.

ing the efficiency of the unit or introducing a foreign color factor. With the proper etching on a prismatic reflector the glare can be almost entirely reduced with a loss in total efficiency of less than one per cent. of what it would be if the same reflector were used without etching.

Window Lighting Reflectors.—The increasing value placed on display window space has stimulated an active interest in the art of show window lighting. This, of course, has abetted the development of special types of reflectors for this kind of lighting. The prismatic types recently developed for window lighting may be classified as asymmetric and concentrating types. The asymmetric reflector is made for use in medium or deep windows. It is so shaped that when it is mounted in a pendent position it will reflect almost all the light off at an angle between 0 deg. and 40 deg. from the vertical. The concentrating type is made for lighting shallow windows and reflects almost all of the light within the 15 deg. zone. These units and the distribution curves obtained with them are shown in Figs. 1A, 1B and 2A, 2B.

Fig. 1A shows the asymmetric reflector which is designed for the 100-watt clear type "C" lamp and is used in medium or deep windows.

Fig. 2A shows the concentrating type of reflector for the 100-watt type "C" clear lamp and is used in shallow or very high windows.

These types installed at the upper outer corner of any window according to the chart shown in Fig. 3 should give satisfactory window lighting. By finding on the chart the horizontal line corresponding to the height of the ceiling and the vertical line corresponding to the depth and noting their intersecting point, the type of reflector can easily be determined.

Prismatic window reflectors embody a great many desirable qualities. They transmit just enough light above the horizontal to brighten up the ceiling, enough at right angles to light a translucent sign or valance at the top of the window, their efficiency is unquestioned and they suffer no depreciation in wear. Another very commendable feature of these reflectors is the fact that they are all made to fit a standard holder, which alone represents considerable saving in many instances.

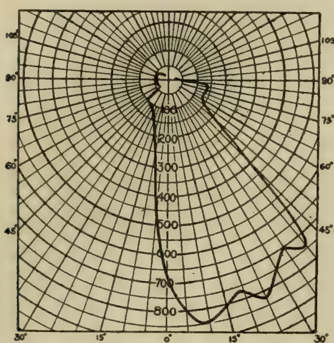


Fig. 1B.—Distribution obtained with 100-watt clear type "C" lamp in an asymmetric prismatic window reflector.

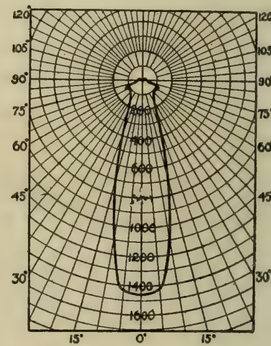


Fig. 2B.—Distribution obtained with 100-watt clear type "C" lamp in a concentrating prismatic window reflector.

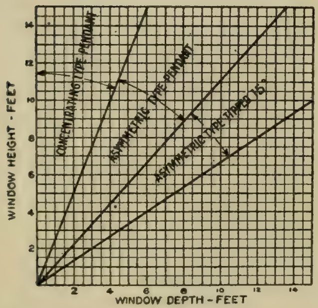


Fig. 3.—Chart for determining proper selection of prismatic window reflector.

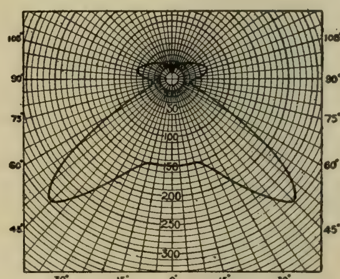


Fig. 5.—Distribution obtained from small-sized reflector refractor. 100-watt clear type "C" lamp used.

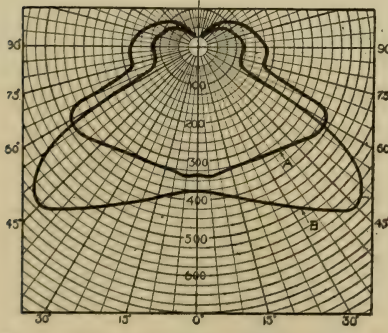


Fig. 6.—Distribution obtained when 200-watt type "C" lamps are used in extensive and intensive reflectors designed for 150-watt type "B" lamps.

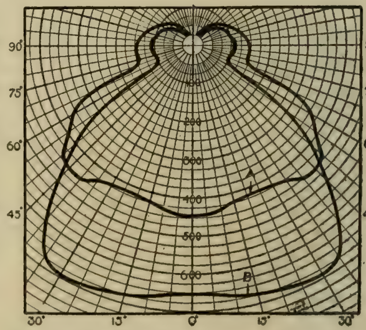


Fig. 7.—Distribution obtained when 200-watt type "C" lamps are used in the proper extensive and intensive reflectors.

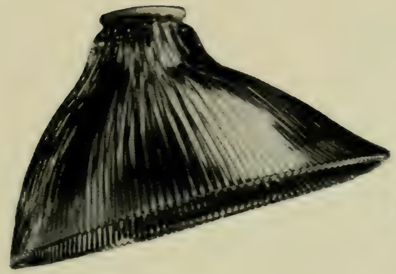


Fig. 1A.—Asymmetric type window reflector.

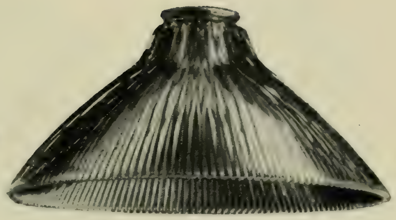


Fig. 2A.—Concentrating type window reflector.

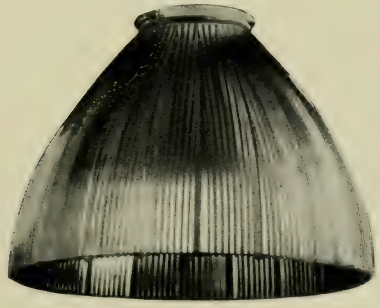


Fig. 11.—Open type prismatic reflector.

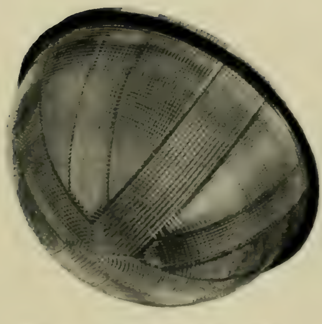


Fig. 12.—Enclosing panel type prismatic unit.

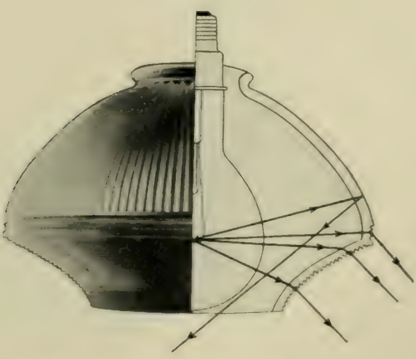


Fig. 4.—Design and principal of reflector refractor unit.

Fig. 8.—Shows parts of urn-shaped semi-direct decorative unit, using prismatic bowl inside.

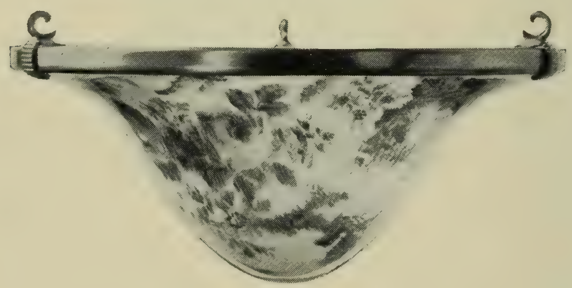


Fig. 9.—Shows apex tpye semi-direct decorative unit.

Fig. 10.—Shows shallow bowl-shaped semi-direct decorative unit.

Reflector-Refractor.—An exceedingly interesting development is introduced in the reflector-refractor unit. It solves the problem of reducing the glare of a type "C" lamp by enclosing it almost entirely, but at the same time controlling its light distribution.

This unit combines on one piece the principles of the reflector and refractor. The upper portion is an efficient prismatic reflector which redirects the light above the horizontal downwards, most of it passing through the bottom opening. The lower portion, which is designated as the refractor skirt is used principally to refract the direct light from the lamp into the directions which are most useful. It also acts as a screen for the bright lamp filament. The design and principle of the reflector-refractor is clearly illustrated in Fig. 4 and its distribution is shown in Fig. 5. It will be noted that the maximum candlepower is obtained at an angle of 45 deg., or in other words it has an extensive curve.

The unit is given a velvet finish which softens the light, but does not seriously affect the efficiency, in fact not more than 13 per cent. of the total flux of the bare lamp is lost. They are made for several sizes of lamps and would prove very effective in lighting offices, stores, libraries, schools, etc., as they are of pleasing appearance, they greatly reduce brightness, provide good ventilating facilities and are most efficient.

Proper Reflector for the Lamp.—To get the most out of prismatic reflectors, it is necessary to have the filament of the lamp held in the proper position; therefore, it follows that prismatic reflectors should be used with the lamp for which they are designed and no other. This point is unfortunately often overlooked and the new or type "C" lamps are too often used with reflectors that were designed for the type "B" lamps.

In Fig. 6 a direct comparison is shown between extensive reflectors designed for the older type 150-watt reflector and the new type 200-watt. Both of these tests are with the 200-watt type "C" lamp. A similar comparison is also shown on intensive type reflectors in Fig. 7. Both of these sets of curves give an idea of the improvement that has been made possible by redesigning the reflectors.

The following table gives some comparative data on these types:

PER CENT. OF TOTAL LAMP FLUX.

	Intensive type			Extensive type		
	0.60°	0-90°	0-180°	0-60°	0-90°	0-180°
Reflectors (VF) designed for type B lamp........	48.0	69.0	90.0	40.0	66.0	91.0
Reflectors designed for type C lamps	59	71	88	56	70	87

Decorative Prismatic Units.—Prismatic reflectors never claimed a distinct place in home lighting until an ingenious method of combining fabric with prismatic glassware in the form of a semi-indirect unit was perfected. The scheme combines three essential parts, an interior prismatic reflector, an outside clear or velvet finish envelope and a fabric which is inserted between them (see Fig. 8.) Figs. 9 and 10 show other designs employing the same principle. By changing the inserted fabric, it is possible to regulate the relative brightness of the semi-indirect bowl and the ceiling, or to match any tapestry or decoration in the room. The combination makes an ideal semi-indirect unit, as the maximum reflection to the ceiling is obtained from the prismatic bowl and the outer appearance can be controlled by the proper selection in color and translucency of the inserted fabric.

The unit is dust proof and though consisting of two bowls gives the impression of but a single bowl. It has almost unlimited possibilities from a decorative standpoint and should appeal strongly to the housewife or small shopkeeper, who wishes to have their lighting in harmony with the surroundings, or who wish to decorate for special occasions without undue expense. The outer bowl being of the exact contour of the prismatic bowl, holds the fabric firmly and smoothly in place. There is no optical contact between the fabric and the prisms to interfere with their reflecting properties.

Panel Reflectors.—Better control of light reflection and diffusion can be obtained in some cases by what is known as the panel arrangement of prisms. This is illustrated in Figs. 11 and 12, which illustrates both the open and enclosing type of units. The general form of prisms used in prismatic reflectors of the so-called stiletto type. These prisms as the name indicates, are somewhat similar to a stiletto, wide at the base and tapering to a

point. They are arranged radially in a reflector, their center line always lying in the plane of the axis of the reflector. In the panel type reflector, the prisms are of the same dimensions throughout their entire length. They are grouped together in the form of panels and are arranged parallel to every other prism in that particular panel. The panel construction, when employed in reflectors, will often obtain better light control as the prisms follow the general contour of the piece itself more closely. Where they are used in hemispheres or in pieces designed to transmit light, a pleasing diffusion and an entirely new effect is obtained.

Nomogram.—A ready aid to proper installation of lighting units has been perfected and is distributed under the name of "Nomogram." It consists of logarithmic scales which are based on values of area in square feet to be illuminated, foot-candle intensity desired, conditions of ceilings and walls, types of glassware and lumens required. The Nomogram also includes the latest ratings of the popular size lamps and spacing constants for the different types of units. Consumption for installations may be easily and rapidly computed for ordinary conditions by passing a line through the known factors on two lines and reading the result on a third line.

Being in itself quite simple and easy to use, it is believed that such forms put in the hands of the layman, will not necessarily bring before him at once the fact that illumination is a science, but that consideration must be given it, if any real value is to be derived.

DISCUSSION.

WARD HARRISON: It seems to me that, especially for home lighting, the wide-spread distribution of light is probably more necessary than in almost any other class of work, because, especially on the second floor, the ceilings in general are low and the average semi-indirect unit, which I know in my own case I have experimented in a second floor bed-room, has never been satisfactory, because you have got a spot of light right over the fixture in the central part of the room, but it certainly did help out in using a dressing table or a chiffonier or any of the usual articles of furniture which are, of course, always placed against the wall. It seems that with these semi-indirect fixtures it should be possible

to get a fairly uniform light over the ceiling which would make a central outlet of real value.

R. ff. Pierce: I know in my own practice it has been frequently difficult and sometimes impossible to obtain sufficiently wide distribution of illumination on the ceiling to produce a really satisfactory effect with indirect lighting, particularly in rooms with low ceilings. I think it is quite an important development, but so much depends upon the evenness of illumination in obtaining satisfactory results.

THE INTERPRETATION OF FORCED LIFE TESTS OF INCANDESCENT ELECTRIC LAMPS.*

BY LEONARD J. LEWINSON.

Synopsis: The first part of the paper discusses the general question of forced tests. The purpose of life tests in general and the objects attained are discussed, and the necessary cost and the length of time required for completion of normal tests pointed out. The method of overcoming these difficulties by means of forced tests and the use of such forced tests to manufacturers, consumers, engineers, inventors, etc., are set forth. The importance of proper means of interpretation of forced tests is emphasized. The methods of making forced tests are described and the necessity for ideal conditions pointed out. The second part of the paper discusses the form of correction curves and refers to the precautions necessary in the use of curves and factors. Examples of the results of misapplication of correction factors are given. A large amount of authorized test data which has been obtained principally under the direction of the author is presented.

Life tests of incandescent lamps in order to be of real value must be comprehensive. The sample lamps must be representative in quality and it has been shown[1] that a considerable number must be tested in order to secure conclusive results. The time required to make tests on lamps, particularly of the Mazda or tungsten type, is extensive. Allowing 24 hours operation per day, and excepting Sundays, a test operating a maximum of 1,000 hours takes very nearly 7 weeks for the burning period alone, and allowance must be made for the necessary preparatory work, the photometric measurements throughout the test and the summary of results when the test is completed.

VALUE OF FORCED TESTS.

Forced tests have been devised primarily for the purpose of surmounting to some extent the obstacle of delay in securing results, which is inherent in normal life tests in which lamps are usually operated at or near their labeled voltage. Incidentally

* A paper presented at the tenth annual convention of the Illuminating Engineering Society, Philadelphia, Pa., Sept. 18-20, 1916.

the cost of testing is reduced, principally because of the decrease in energy consumption.

In view of these advantages, recourse to forced life testing is frequent, even though such tests may be considered as make-shifts. If there is any virtue at all in a forced life test, it must be of value to those who would find normal tests of use. J. W. Howell[2] states that forced life tests are highly valuable when properly interpreted. Thus such tests are useful to lamp manufacturers. Lamp consumers also make use of such tests. Middlekauff, Mulligan and Skogland[3] state that life tests made under their supervision at the Bureau of Standards at Washington are made at efficiencies corresponding to a range of 0.9 to 0.95 watt per candle for tungsten lamps which are probably rated at from 0.95 to 1.15 watts per candle. Minick[4] states that the Pennsylvania Railroad Company, a large consumer of incandescent lamps, depends largely upon excess voltage or forced test to determine life of test samples. Experimenters, lamp engineers, inventors find use in forced tests.

Those who have had experience with forced tests, however, realize fully their shortcomings. A forced test is of little value unless proper means of interpretation of the results are at hand. The unreliability of forced tests made under certain conditions will be pointed out in connection with the test results given at the end of this paper.

FORCED TEST METHODS.

In discussing methods and results of forced tests in the following pages, watts per mean horizontal candlepower will be used to indicate specific consumption, because all of the tests made in the past have involved measurements of mean horizontal candlepower, manufacturers having rated lamps on this basis. Now that integrating sphere photometers are available, the measurement of total flux is a simple matter, and at the Electrical Testing Laboratories life tests are now being conducted on the basis of stated lumens per watt.

Methods of making forced tests differ somewhat among various laboratories engaged in this kind of work. In general the principle involved is the operation of the lamps at some voltage above the normal or labeled voltage. It is in the determination

of this voltage that the chief differences occur. The following are the principle methods used:

1. The lamps are measured to determine the voltage at some stated watts per candle, which may be the standard rated watts per candle for each type and size of lamp, or which may be a constant value for a given type. For example, this stated watts per candle has been taken as 1.23 (corresponding to approximately 8 lumens per watt) for tungsten lamps. The voltage obtained by this method is then multiplied by a constant factor to determine the forced test voltage; for example, a forced test voltage in common use has been 130 per cent. of the voltage at which tungsten lamps consume 1.23 watts per candle.

2. A standard forced test watts per candle is specified and the voltage to give this watts per candle is determined in one of three different ways:

a. Lamps are measured at some stated voltage, usually the labeled volts, to determine accurately the candlepower and watts per candle, and the forced test voltage is determined by computation using standard characteristic curves.[5]

b. The forced test voltage is determined by actual photometric measurement at the specified watts per candle. In this method it is necessary to make trial determinations.

c. A combination of methods *a* and *b* in which the computed value is checked by actual photometric measurement.

After lamps are placed on life test at the forced voltage determined by one of the methods enumerated above, additional photometric measurements throughout life are made, either at the labeled or at the forced voltage. Measurement at labeled voltage makes for consistency and simplification of records and photometric determinations.

In general the methods used in making normal life tests apply in forced life tests. It is important to have a sufficient number of photometric measurements to determine the performance curve and therefore the measurements are made at very much closer intervals than in the normal tests. The importance of close voltage regulation in all life tests has been frequently pointed out. There is no necessity to dwell upon this point further except to state that, with the added element of uncertainty

of life correction factors which enter into forced life tests, there can be no relaxation from the most rigid voltage maintenance.

SOME PUBLISHED CORRECTION FACTORS.

Comparatively little data have been published on the subject of correction factors. As early as 1880 manufacturers' tests showed that the life of carbon filament lamps varied as the 3.65 power of the candle-power. A publication of the General Electric Company reported in the *Electrical World* in 1897[6] gives correction factors applying to carbon lamps for voltages varying from 1 to 6 per cent. above the normal. J. W. Howell[7] in 1910 called attention to the fact that the life of carbon filament incandescent lamps varied as 3.65 power of the candlepower and that the indications at that time were that this exponent was a constant for all types of filaments developed to date. Correction factors for tungsten lamps given by Howell indicated that the life varied approximately as the 6.7 to 6.8 power of the watts per candle. Merrill, Cooper and Blake[8] stated that the curve showing the relationship between life and watts per candle of tungsten lamps conformed very rigidly to a pure parabolic law within a range of 0.67 to 1.25 watts per candle and gave 6.65 as the exponent. G. P. Cowan[9] gives exponents for tungsten lamps of 3.66 for the life-candlepower relation and 14 for the life-voltage relation. This latter corresponds to a life-watts per candle exponent of approximately 7. Middlekauff, Mulligan and Skogland[10] give a life-watts per candle exponent of 7.4. In a discussion of the subject the author[11] suggests that this exponent applies only for tungsten lamps of the larger sizes (25 to 100 watts) and that a lower exponent is indicated for smaller lamps.

A word concerning the form of the life characteristic curves—Cady[12] and Edwards[13] have shown that the characteristic curves of relationship candlepower, volts, watts, etc., of incandescent lamps are not simply parabolic curves of the form

$$x = ay^n,$$

but that the exponent n is a variable and dependent upon the voltage. Edwards[14] shows, however, that within a limit of 15 per cent. above and below normal voltage the error in calculated results of candlepower, watts and watts per candle involved in the use of a constant exponent is not greater than about 1 per

cent. While the writer has little authoritative data available showing the variation in the life exponent, it is reasonable to believe that this life exponent may be a variable, but that the use of a constant exponent over a limited range will yield results which are not subject to a considerable error. Furthermore, forced life tests are usually made at certain specified watts per candle which represent a certain percentage above rated efficiency, and the exponents which are used in making the corrections are derived from tests which have been forced to the same degree and compared with normal tests. The equation most conveniently used is

$$\frac{\text{Life}_1}{\text{Life}_2} = \left(\frac{\text{wpc}\cdot_1}{\text{wpc}\cdot_2}\right)^b.$$

which may be adapted to

$$\frac{\text{Life}_1}{\text{Life}_2} = \left(\frac{\text{lumens per watt}_2}{\text{lumens per watt}_1}\right)^b,$$

thus the same exponent may be made to apply. If life$_1$, watts per candle$_1$ and lumens per watt$_1$ be taken as the normal values, and life$_2$, watts per candle$_2$ and lumens per watt$_2$ be taken as the forced values, then the ratio to be raised to the power b will always be greater than unity, thus affording convenience in calculation.

DISCUSSION OF TEST DATA.

The forced life tests conducted at Electrical Testing Laboratories during the past few years have been made in general on lamps selected in two ways. Prior to January 1, 1915, a single lamp of a given size and type was selected from among each lot consigned by the manufacturer to the consumer, the size of the lot varying from 500 to 2,000 lamps. Every alternate lamp so selected was tested at normal efficiency, the remaining lamps being tested at forced efficiency. After January 1, 1915, this practice was changed and all of the lamps selected by the lot system were subjected to normal test. The forced test samples were taken each month as representative of the latest factory product. There is, therefore, the possibility that comparisons of normal to forced tests made on lamps selected by the second method are subject to some question because the normal and

TABLE I.—EXPONENT b DERIVED FROM NORMAL AND FORCED TESTS, MAZDA INCANDESCENT LAMPS.

	1911–12		1912–13		1913–14		1914–15				1915–16		1915
Watts	wpc* ratio	Exponent	wpc* ratio	Exponent	wpc* ratio	Exponent	wpc* ratio	Exponent	wpc* ratio	Exponent	wpc* ratio	Exponent	As-signed values
10 s 14	—	—	—	—	1.55	6.4	1.51	5.9	1.56	5.6	1.59	5.6	6.1
10 s 17	—	—	—	—	—	—	1.46	5.9	1.53	6.5	1.53	5.4	6.4
15	—	—	1.46	6.3	1.42	6.8	1.39	7.1	1.52	7.1	1.53	6.4	6.8
20	—	—	1.39	6.5	1.35	7.5	1.30	7.1	1.48	7.1	1.46	6.8	7.2
25	1.33	6.9	1.33	6.1	1.27	7.3	1.26	7.2	1.39	7.0	1.39	7.0	7.3**
40	1.25	7.2	1.25	7.7	1.22	7.6	1.22	7.2	1.37	7.5	1.37	7.2	7.4**
50	—	—	—	—	—	—	—	—	—	—	1.33	7.3	—**
60	1.20	7.5	1.23	7.2	1.24	7.5	1.26	7.4	1.36	7.7	1.33	7.3	7.5**
100	1.20	7.3	1.20	7.4	1.24	8.0	1.28	7.5	1.21	7.2	1.26	7.4	7.8**

* The wpc ratio is the ratio of normal to forced watts per mean horizontal candlepower. The same exponent may be employed if the ratio of *forced* to *normal* lumens per watt be used.

** 7.4 actually used in 1915-6.

forced test samples might not always be contemporaneous. Experience has shown, however, that the number of samples tested has been in practically all instances so large and has covered so long a period of time that such effects have probably been counteracted.

Table I shows the average exponents obtained for Mazda lamps of 10 to 100-watt sizes, tested for useful life during the past five years. The ratio of normal to forced watts per candle is also shown in order to indicate the extent of forcing. In preparing these averages there were eliminated lamps of certain types of construction having exponents which were not at all consistent with those obtained for other types of construction in the same size of lamp. It is seen in general that there is a very considerable tendency toward a smaller exponent in the case of lamps of the smaller sizes. The table includes also the assigned value of exponents which has been used at the laboratories during the past year. It should be stated that in preparing these assigned values the results of tests made prior to 1913-14 were not considered, inasmuch as the lamps manufactured prior to that time were of radically different types of construction in many cases. It may be stated here that prior to 1914 the exponent 6.65 was in rather general use, although it was realized that this exponent gave conservative normal life values, particularly in lamps of the larger sizes. Reference to the 1914-15 exponents shows that the exponents derived from the high forced tests were substantially the same as those from the moderate forced tests.

In order to illustrate the range of exponents obtained in sizes of lamp of which a very considerable number were tested, Table II has been prepared. This shows exponents for 60 and 100-watt lamps of various types of construction which are indicated by means of code numbers. In no cases are these exponents derived from tests of less than ten lamps in each of the normal and forced tests, and in most cases the number of lamps tested was more than fifty at each efficiency.

Particular attention is called to the exponent for construction No. 6. A similarly low exponent was obtained for 100-watt lamps of the same construction tested at about the same time.

TABLE II.—EXPONENT *b* DERIVED FOR 60 AND 100-WATT LAMPS OF VARIOUS TYPES OF CONSTRUCTION.

Arbitrary construction identification	Exponent 60-watt	Exponent 100-watt
23	7.3	7.4
16	7.6	7.4
14	7.5	7.0
13	7.5	7.9
12	7.2	7.8
7	7.2	7.5
6	5.6	6.2
5	—	7.2
4	—	7.3
3	7.2	7.0
2	—	8.2
1	7.5	7.3

During the past year questions have been raised as to the propriety of using exponents as low as those shown in Table I for 10-watt lamps. The results for 1915-16 not being available, a special check test was made. In this test two groups of lamps were submitted; one picked at random from the product and one manufactured especially and carefully selected. In the first instance the exponent determined was 6.6. In the instance of the specially selected lamps the exponent was 7.2. The first exponent, although larger than that indicated in Table I, justified the use of the small exponent for regular product lamps. This practice was vindicated by the exponent determined in 1915-16 from tests of 230 lamps of regular product for which an exponent of 5.6 was obtained.

Investigations of the records have indicated that correction factors which apply for tests of useful life are not applicable to total life or to life to 80 per cent. of the initial candlepower, failures being eliminated. As an example of this Table III is given showing exponents derived in three ways; (1) life to 80 per cent. with all burn outs eliminated; (2) useful life, being the life to 80 per cent. or earlier burn out; (3) total life. 1915-16 exponents are compared to those previously determined. Lamps of the very small sizes have been eliminated because the useful and total life are practically coincident. It is plain that the total life exponent is lower than that for useful life, which in turn is lower than that for the life to 80 per cent. only. This leads to the question as to

TABLE III.—Comparison of Exponent b Total, Useful and 80 Per cent. Life.

	1915–16			Previously determined		
Watts	Total life	Useful life	80 per cent. life	Total life	Useful life	80 per cent. life
25	7.1	7.0	7.2	7.3	7.2	7.5
40	7.0	7.2	7.2	7.3	7.4	7.5
60	6.8	7.3	7.4	6.6	7.5	7.6
100	6.8	7.4	7.6	6.9	7.8	7.9
Numerical average	6.9	7.2	7.4	7.0	7.5	7.6

whether the correction factor is not a function of the percentage of burned out lamps which go to make up the useful life group. Fig. 1 shows a series of circles, the center-points indicating the

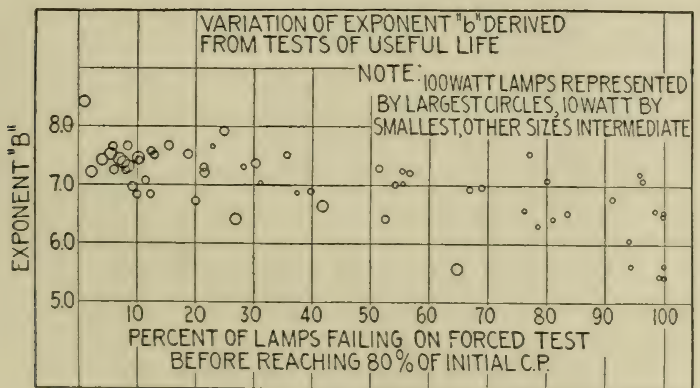


Fig. 1.

relation between the exponent and the per cent. of lamps burned out for several different sizes of lamps. The circles are graded according to size of lamp, from 100 to 10 watts. There is evidence that as the percentage of failure increases, the exponent decreases in any given size of lamps, and an unmistakable indication that as the size of the lamp decreases the exponent decreases, regardless of whether or not all of the lamps fail before 80 per cent.

One fact has stood out prominently in the study of correction factors. Factors which have been determined for a product of average quality fail absolutely when applied to a product which is characterized by certain defects. The low exponent for 60-

watt lamps of construction No. 6 which was indicated in Table II is an example of this. When the faulty construction was corrected, the exponent became more nearly what was to be expected for lamps of this size as indicated by the exponent for construction No. 7. Occasionally a type of construction which is successful in one or two sizes of lamps may not succeed at first in some other type. In these circumstances care must be taken in the use of correction factors. As an example, it was found that while an exponent of 7.1 was found for 40 and 60-watt lamps of a certain type of construction manufactured at a given period, the value for the 100-watt lamp was 5.9. Again take the example of the 10-watt lamps. Had the exponent derived from the special test of specially constructed lamps been applied to lamps of regular product, the errors would have been very large. Over a range of very nearly 58 per cent. in watts per candle the life obtained by using an exponent of 7.2 would be 65 per cent. greater than that obtained by means of the exponent 6.1 which is the assigned value from regular product tests as shown in Table I.

It is of interest to note that the above examples of unusual exponents derived from tests of lamps which were of defective or unusual construction may be lower or higher in value than exponents which might be expected from tests on lamps of normal product. In the main, these exponents have been low; therefore, the use of a higher exponent previously determined departs from the conservative, in that it yields a life value which is too high. In the past, manufacturers of incandescent lamps have experienced serious errors due to the use of exponents which were too high.

In the tables given, exponents for 150 and 250-watt lamps have been omitted. It has been found practically impossible to depend upon correction factors for these types. The construction is such that the operation of the bulb blackening preventive is quite erratic and appears to work only at the proper temperatures. Table IV shows a few examples of exponents derived from tests of 150 and 250-watt lamps.

Harrison and Edwards[15] have shown that bulb blackening preventives of certain varieties will operate properly only at certain temperatures. If the temperature is raised to the same degree in a forced test on two groups of lamps of slightly different con-

struction it is quite possible that considerable differences in performance will result so that forced test factors obtained in the one instance will not apply to the other.

TABLE IV.—EXPONENT b DERIVED FROM TESTS ON 150 AND 250-WATT MAZDA LAMTS.

Year	Make	Construction identification	150-watt wpc* ratio	150-watt Exponent	Construction identification	250-watt wpc* ratio	250-watt Exponent
1915–16	A	18	1.12	8.5	17	1.12	10.1
	B	--	—	—	18	1.12	9.5
	C	17	1.13	13.9	17	1.13	7.8
1914–15......	A	18	1.13	7.4	17	1.12	8.8
1912–13......	A	2	1.16	7.6	8	1.10	16.7
	A	9	1.17	8.2	9	1.12	8.3

* The wpc ratio is the ratio of normal to forced watts per mean horizontal candlepower. The same exponent may be employed if the ratio of *forced* to *normal* lumens per watt be used.

The applicability of factors obtained from tests on lamps made at one factory, to lamps made at another factory must be proven before they are used indiscriminately. Examples of this are shown in Table V, in which exponents obtained from lamps made at three different factories are given. It is true that differences in construction enter into this comparison in some instances, but the lamps were of contemporaneous manufacture and well illustrate the point.

TABLE V.—EXPONENT b, LAMPS FROM THREE FACTORIES.

	Factory X	Factory Y	Factory Z
10-watt S14	5.6	7.4	6.5
15-watt	6.4	6.9	6.5
25-watt	7.0	7.2	6.7
40-watt	7.2	7.3	6.9
50-watt	7.3	7.3	7.1
60-watt	7.3	7.4	7.0
100-watt	7.4	7.8	6.8

Fig. 2 has been prepared to show graphically the percentage of error involved in the use of a constant exponent for lamps of all sizes and types. The constant exponent chosen has been 7.4 because this figure has been referred to most frequently in recent publications. It is seen that as the range in watts per candle increases, the error increases substantially.

As a final example of the danger of misinterpretation of forced test results in the absence of proper correction factors, a test on 7.5-watt lamps is cited. Twenty lamps taken at random from among the first lamps of this size manufactured were separated into two groups, ten lamps being operated at 0.87 watt per mean horizontal candlepower, and ten at 1.50 watts per mean horizontal candlepower. Using the exponent 6.1, which had previously been assigned to 10-watt lamps, it might be expected that the normal life would be approximately 28 times the forced life. As

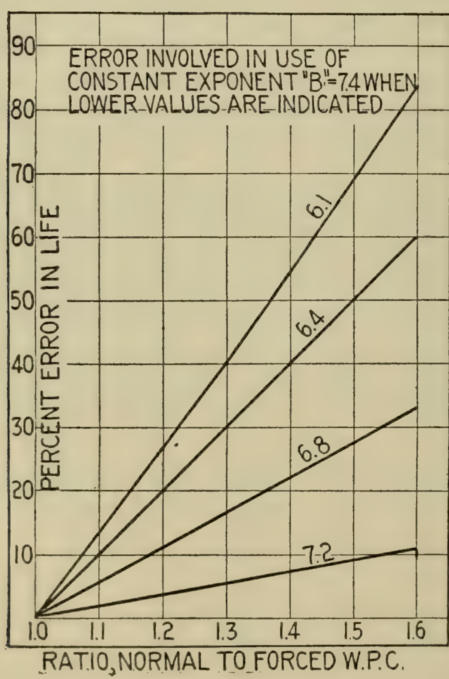


Fig. 2.

an actual fact, the life of the lamps tested at normal efficiency was only 4¾ times the life of the lamps forced tested. These lamps were found to be of unsuitable type of construction—afterwards corrected. Nevertheless, the exponent determined for 7.5-watt lamps made by one manufacturer was in the neighborhood of 4 during the early stages of production.

RECAPITULATION.

Summarizing it may be said that forced tests of incandescent lamps are unquestionably of value in reducing the time required to make the tests and thereby the delay in obtaining life values of lamp product; and to some extent in reducing cost of testing. Forced tests are predicated upon intimate acquaintance with manufacturing conditions and upon characteristics of lamps, and correction factors determined under one set of conditions must not be applied under other conditions unless their applicability has been proven. There is a general tendency toward a lower exponent for lamps of smaller sizes, and it also appears that the exponent decreases to some extent as the proportion of lamps which fail before dropping to 80 per cent. of initial candlepower increases. Exponents determined from ultimate life tests are smaller than those determined from useful life tests of lamps of the same type and sizes, excepting, of course, when the useful and ultimate life are identical in value. Underlying all of the above, forced tests must be made with at least as much care as normal tests and under the very best conditions obtainable.

The material used in the preparation of this paper has been made available through the courtesy of the Lamp Committee of the Association of Edison Illuminating Companies. The tests were made at Electrical Testing Laboratories. Many of the results have been the subject of discussion with representatives of the manufacturers whose lamps were tested.

LIST OF REFERENCES.

1. Variables of Lamp Testing Results—Millar and Lewinson, Electrical Review and Western Electrician, vol. 68, p. 1062, June, 1916.
2. Metal Filament Lamps—J. W. Howell, Trans. A. I. E. E., vol. 29, p. 935, 1910.
3. Life Testing of Incandescent Lamps at the Bureau of Standards—Middlekauff, Mulligan and Skogland, Trans. I. E. S., vol. 10, p. 842, 1915.
4. Discussion of (3)—Trans. I. E. S., vol. 10, p. 839, 1915.
5. Characteristics of Mazda Lamps—Evan J. Edwards, General Electric Review, vol. 17, p. 282, March, 1914.
6. Electrical World, vol. 30, p. 763, 1897.
7. Metal Filament Lamps—J. W. Howell, Trans. A. I. E. E., vol. 29, p. 935, 1910.

8. Discussion of (2).
9. Incandescent Electric Lamps—G. P. Cowan, Wisconsin Engineer, p. 361, May, 1912.
10. Life Testing of Incandescent Lamps at the Bureau of Standards—Middlekauff, Mulligan and Skogland, Trans. I. E. S., vol. 10, p. 842, 1915.
11. Discussion of (3).
12. The Relation Between Candlepower and Voltage of Different Types of Incandescent Lamps—F. E. Cady, Trans. I. E. S., vol. 3, p. 459, 1908.
Luminous Intensity and Energy Relations in Incandescent Lamps—F. E. Cady, Electrical Review and Western Electrician, vol. 59, p. 1087, 1911.
13. Characteristics of Mazda Lamps—Evan J. Edwards, General Electric Review, vol. 17, p. 282, March, 1914.
14. Characteristics of Mazda Lamps—Evan J. Edwards, General Electric Review, vol. 17, p. 282, March, 1914.
15. Recent Improvements in Incandescent Lamp Manufacture—Ward Harrison and Evan J. Edwards, Trans. I. E. S., vol. 8, p. 535, November, 1913.

DISCUSSION.

G. W. Middlekauff: I wish to express my appreciation of this paper and to congratulate the author upon the large amount of important data he has collected.

In the main, the results here given are in substantial agreement with those we have obtained at the Bureau of Standards. In our life testing of the vacuum tungsten lamps purchased by the Federal Government, most of which have been of the 25 to 250-watt sizes, it has been the custom to slightly force the lamps and correct the life to normal by the use of 7.4 as a life-watts per candle exponent. The lamps we test are representative samples selected strictly in accordance with standard specifications and number about 3,500 annually.

The mean corrected life values obtained for the 25 to 100-watt sizes by the use of 7.4 have each year agreed so well with mean normal values that we have had no reason to change this exponent which we see is the one now in use also at the Electrical Testing Laboratories. With the 150 and 250-watt sizes, our experience has been the same as that of Mr. Lewinson, but the variations, as found at different times, in the exponents which

apply to these sizes have been regarded as due principally to the lack of a sufficient number of samples at our command to give good average results. Although we have received and force-tested but a small number of samples below the 25-watt size, and tested none at normal watts per candle, the relatively high corrected life values obtained indicate that the correct value for the exponent is probably less than 7.4.

In 1914-15 we made a test of about 1,000 25-, 40-, 60- and 100-watt lamps in order to make a direct determination of their exponents. As the lamps were received from the inspector alternate ones were taken for the normal and forced test lots, respectively, one-half of each size being selected from each of two different companies. The average watts per candle ratio of the two test lots was about 1.2. Although there was a considerable variation in the life values of the individual lamps, it was found that, not only did the exponents for the different sizes come out as nearly equal as could be reasonably expected, but there was practically no difference between the exponents which applied to the corresponding lamps of the two companies.

In 1915-16 another normal and forced test was made of about 500 25,- 40- and 60-watt lamps, all selected at the beginning of the season and in the same manner as in the previous test, one-half being again taken from each of the same two companies. This time the lamps of each size were divided into three groups and the separate groups were run at 1.0 watt per candle, 0.9 watt per candle and 0.8 watt per candle, respectively. Of the 25-watt lamps, practically all burned out above 80 per cent., but the lamps of the one company gave considerably shorter life than those of the other company. Of the 40-watt size, about one half of the one company's lamps burned out above 80 per cent. while the other company had practically no burnouts above 80 per cent. Of the 60-watt size, no lamps of either company burned out above 80 per cent. When the forced values were corrected to normal by the use of 7.4, it was found (1) that there was good agreement between the normal and forced life values for each size; (2) that this exponent held as well for the burnouts above 80 per cent. as for the 80 per cent. lamps; and (3) that there was no appreciable difference between the exponents for the corresponding lamps of the two companies although, of the 25- and

40-watt sizes, there was a considerable difference between the mean life values for the two makes of lamps.

In the determination of life-efficiency exponents, too much emphasis cannot be placed upon the importance of using a large number of lamps. The destruction of the lamps in the test, of course, makes it impossible to find what life any given lamp would give at more than one efficiency. The best that can be done is to find the average life for different groups of such lamps, one group burned at one efficiency, another group at another of the chosen efficiencies, etc. On account of the large variations in life among individual lamps, even at exactly the same efficiency, it is evident that, unless the number of lamps included in the test is sufficient to give good average results, large variations in the life-efficiency relation, as found with different test lots, must be expected.

Equal in importance to the proper number of lamps to be used is the similarity of the groups to be compared. This cannot be assumed if the lamps composing the groups are not contemporaneous in manufacture. In our test of 1915-16, if we had selected one group from the samples received early in the season and the other two groups from the samples received several months later, we would have introduced large errors into our results because of the differences in quality of the product during these different periods.

It does not seem unreasonable to expect that lamps made under the same specifications, in the same types and sizes, and of the same material having the same characteristics should have the same life-efficiency relation, although made in different factories. However, Mr. Lewinson has given in Table V data to show that a difference may be expected. I am therefore interested to know how nearly the author, judging from his experience, would expect to repeat these data on successive tests of similar lamps, and if the differences persist how he explains them. I would like him to state also how he accounts for the low exponents which he found for the groups designated "6" in Table IV.

L. G. JARRETT: I can agree with Dr. Middlekauff in saying that from the 25- to the 100-watt types, inclusive, it would be difficult for manufacturers to correct their results by using an

exponent of very near 7.4, but when we take into consideration the 10,- 15,- and 25-watt types, there seems to be considerable variation between the different laboratories. For instance, I notice Mr. Lewinson states that for the 10-watt lamp he is using an exponent of 6.1. The tests we have made seem not to check this very well. I will designate three laboratories by A, B and C. Laboratory A finds the exponent to be 6.7; laboratory B finds the exponent to be 6.8, and laboratory C finds the exponent to be 6.9. Mr. Lewinson is using the exponent 6.1. All of these different factory tests I have given are first a forced test around 0.9 and the second not being normal but around 1.2. I would like to ask Mr. Lewinson if he thinks it would be a good idea to go into this matter further and make our tests at 1.2 and normal also, which is 1.35. I would also like to have Mr. Lewinson state just what exponent he thinks should be used on a Mazda lamp, what is the forced test to be used.

W. M. SKIFF: It has been found that very little reliability can be placed in forced tests on coiled filament gas-filled lamps because of the wide variation in results as compared with those obtained on vacuum lamps. Because of this inherent quality practically all of our tests on gas-filled lamps are made under normal conditions.

Mr. Lewinson has covered, quite thoroughly, the methods used in obtaining the life-efficiency exponent "b", and also the limitations of its use.

It is necessary for lamp manufacturers to obtain such an exponent or a series of exponents for different types of lamps for reasons brought out in Mr. Lewinson's paper. Their limitations and the care with which they should be applied, therefore, are best appreciated by those who have given considerable attention to this subject. It appears, therefore, that while the following statement in the paper might apply in some specific cases, it would not apply to lamp manufacturers in general.

> "In the past, manufacturers of incandescent lamps have experienced serious errors due to the use of exponents which were too high."

It has always been the policy of the National Laboratories, in Cleveland, to use a conservative exponent, and so far as I know

there have never been any serious errors, due to the use of exponents which were too high.

Life-efficiency data is obtained at regular intervals throughout the year, and have been cumulative for the last several years. In this way, the general trend from month to month, and year to year, is studied with the result that wide variations from the average conditions may nearly always be accounted for by changes in construction or methods of manufacture. It may be of interest to compare the values of "b" which have been used during the year 1916, by the National Lamp Works, with those shown in Table I of Mr. Lewinson's paper:

Watts	Exponent "b"
10-w. S-14	6.7
10-w. S-17	6.7
15	6.8
20	7.0
25	7.1
40	7.2
50	7.2
60	7.3
100	7.4

It will be seen that the two sets are in very good agreement, and that with two exceptions, the National values are perhaps a little more conservative.

J. L. MINICK: I want to impress upon everyone the importance of working our reliable quick tests. There are many forms that purchase lamps in large quantities, and while I do not think any of them want to be understood as wanting a product better than that given to others, yet I do think they all want to secure a product that is representative of the average run of the product. That rating of products can be secured usually only by some method of quick testing. Our company purchases approximately a million lamps a year. We do not like to tie up our capital in extra stock for a period of more than two months; consequently it is absolutely necessary, if we are going to test our lamps at all, to have a quick test, and that leads me to compliment the author of the paper on the work he has done and to urge upon others the importance of continuing this work so that we may eventually have tests which are

applicable to practically all of the products of practically all manufacturers. One unfortunate feature of the life test at the present date is that the time element of testing is a little bit longer than desirable by the purchaser. Most lamps now require anywhere from 125 to 200 hours test. At 10 hours a day, which is the operating period for a good many of the laboratories, that means 20 days in the case of the long lamps, which works a hardship on the manufacturer by compelling him to hold those lamps in storage there awaiting the results of the test. It would be very desirable if something could be done to shorten the test so that it would not exceed 100 hours.

Preston S. Millar: Perhaps a word might be in order in regard to the significance and purpose of the forced tests which are being made at our laboratories and are described in Mr. Lewinson's paper. As stated, these tests are made principally for the Associated Edison Illuminating Companies, a very large purchaser of incandescent lamps. They are made largely because the lamp manufacturers make forced tests and to a considerable extent abide by the results. They are obliged to be guided by the forced test, because they cannot wait for normal test results, and in self-defense we have been obliged to make forced tests to follow the manufacturers. We accept forced tests on incandescent lamps only with the greatest caution and in cases where we have a well established correction factor based upon lamps of the same manufacture and known construction. The instance of the very low exponent commented upon by one speaker, where the value Mr. Lewinson has shown is in accord with the value used in manufacturers' laboratories, is a case in point. We know very well and I think all the manufacturers know why that exponent is very low, and we know just what lamp to apply that exponent to, and which lamp not to apply it. Unless we had such knowledge we could not intelligently use forced tests on that particular type of lamp. We never make forced tests if we can help it without accompanying them by normal tests. We use forced tests as the merest indication. They are to be avoided unless full knowledge is had of the manufacturing conditions and all the elements necessary to make an intelligent application of the results, and unless later they can be verified by normal tests.

L. J. LEWINSON: Taking up first Dr. Middlekauff's discussion: With regard to 150- and 250-watt lamps, while it is true that a relatively small number of lamps of these sizes are tested, it is my opinion that the variable exponents found are due principally to the erratic performance of individual lamps. Dr. Middlekauff makes the point that to secure authoritative correction factors a large number of lamps should be used, and that those used in normal and forced tests should be contemporaneous in manufacture. With these conditions fulfilled in his tests he has combined the test results and has determined values of exponents which agree substantially with the 7.4 figure. In tests at the Electrical Testing Laboratories which have been combined in the same way we have also checked the 7.4 exponent very closely, as shown in the paper. Our analyses, however, have shown that certain details of construction affect the exponent seriously. Perhaps if the tests made at the Bureau of Standards were analyzed along the lines which we have pursued, similar differences might be found. The necessity for contemporaneous construction is plainly evident; the need for a large number of samples is understood. In our own tests from 10,000 to 12,000 lamps per year are used, half tested at normal and half at forced efficiency, and I can safely say that practically every exponent shown in this paper has been determined from a test of at least 50 lamps. In the 25- to 100-watt sizes the large majority of tests have included from 100 to 600 lamps per group. The question of type of construction remains the important detail, which does not seem to appear in Dr. Middlekauff's discussion, inasmuch as he seems to have combined all of his test results on a given size of lamps.

Our more extensive testing covering as it does more than three times the number of lamps referred to by Dr. Middlekauff permits us to make more complete analyses with regard to exponents derived from useful and total life. Of course when the divergence between total and useful life is small the difference in exponents derived from such tests is small.

In answer to the specific questions, would say that we feel that with smaller lamps we would expect to repeat our data within the ordinary precision of life testing work. With regard to the

differences shown as between lamps made in different factories, this is but a variation of the general question of construction.

With reference to the last question as to how we account for the low exponents found in the groups designated "6" in Table IV, I would prefer not to answer this question, especially as manufacturers' representatives present at this meeting have not taken the opportunity to answer it.

Answering Mr. Jarrett, in regard to the 10-watt situation in Table V, the exponent for the product of one factory is shown as 7.4, indicating that a certain group of lamps from at least one factory has a relatively high exponent for this size of lamp. The paper has also referred to a test on 10-watt lamps specially selected, from which a higher exponent was obtained than from regular product tests. In this very point may lie the reason for some of the differences that we have found. The lamps selected by other testing organizations may have been specially inspected before selection, or perhaps given the regular factory inspection and faulty lamps eliminated, while on our tests showing the lower exponents the lamps are selected absolutely at random from the product as shipped, and, incidentally, before we make our inspectional tests.

With regard to Mazda C lamps, Mr. Skiff has substantially answered the question. We have not attempted to make any forced tests at all on Mazda C lamps. The life testing of these lamps, many of which are high wattage, is expensive and in view of the experience of other laboratories, we believe that we do better in expending the available funds on normal tests which will give us good value for the money, at least until it is possible to make forced tests which will yield results of reasonable value.

1916 REPORT OF THE COMMITTEE ON NOMENCLATURE AND STANDARDS OF THE ILLUMINATING ENGINEERING SOCIETY.*

DEFINITIONS.

1. **Luminous Flux**, F, is radiant power evaluated according to its visibility; *i. e.*, its capacity to produce the sensation of light.

2. **The visibility**, K_λ, of radiation, of a particular wave-length, is the ratio of the luminous flux to the radiant power producing it.

3. **The mean value of the visibility**, K_m, over any range of wave-lengths, or for the whole visible spectrum of any source, is the ratio of the total luminous flux (in lumens) to the total radiant power (in ergs per second, but more commonly in watts).

4. **The luminous intensity**, I, of a point source of light is the solid angular density of the luminous flux emitted by the source in the direction considered; or it is the flux per unit solid angle from that source.

Defining equation:

$$I = \frac{dF}{d\omega}$$

or, if the intensity is uniform,

$$I = \frac{F}{\omega},$$

where ω is the solid angle.

5. Strictly speaking no point source exists, but any source of dimensions which are negligibly small by comparison with the distance at which it is observed may be treated as a point source.

6. **Illumination**, E, on a surface, is the luminous flux-density on that surface, or the flux per unit of intercepting area.

Defining equation:

$$E = \frac{dF}{dS},$$

or, when uniform,

$$E = \frac{F}{S},$$

where S is the area of the intercepting surface.

* A report presented at the tenth annual convention of the Illuminating Engineering Society, Philadelphia, Pa., Sept. 18-20, 1916.

7. Candle—the unit of luminous intensity maintained by the national laboratories of France, Great Britain, and the United States.[1]

8. Candlepower—luminous intensity expressed in candles.

9. Lumen—the unit of luminous flux, equal to the flux emitted in a unit solid angle (steradian) by a point source of unit candlepower.[2]

10. Lux—a unit of illumination equal to one lumen per square meter. The cgs. unit of illumination is one lumen per square centimeter. For this unit Blondel has proposed the name "Phot." One millilumen per square centimeter (milliphot) is a practical derivative of the cgs. system. One foot-candle is one lumen per square foot and is equal to 1.0764 milliphots.

The milliphot is recommended for scientific records.

11. Exposure—the product of an illumination by the time. Blondel has proposed the name "phot-second" for the unit of exposure in the cgs. system. The microphot second (0.000001 phot-second) is a convenient unit for photographic plate exposure.

12. Specific luminous radiation, E′—the luminous flux-density emitted by a surface, or the flux emitted per unit of emissive area. It is expressed in lumens per square centimeter.

Defining equation:

For surfaces obeying Lambert's cosine law of emission,

$$E' = \pi b_0.$$

13. Brightness, *b*, of an element of a luminous surface from a given position, may be expressed in terms of the luminous intensity per unit area of the surface projected on a plane perpendicular to the line of sight, and including only a surface of dimensions negligibly small in comparison with the distance at which it is observed. It is measured in candles per square centimeter of the projected area.

Defining equation:

$$b = \frac{dI}{dS \cos \theta}.$$

(where θ is the angle between the normal to the surface and the line of sight.)

[1] This unit, which is used also by many other countries, is frequently referred to as the international candle.

[2] A uniform source of one candle emits 4π lumens.

14. Normal brightness, b_0, of an element of a surface (sometimes called specific luminous intensity) is the brightness taken in a direction normal to the surface.[3]

Defining equation:

$$b_0 = \frac{dI}{dS},$$

or, when uniform,

$$b_0 = \frac{I}{S}.$$

15. Brightness may also be expressed in terms of the specific luminous radiation of an ideal surface of perfect diffusing qualities, *i. e.*, one obeying Lambert's cosine law.

16. Lambert—the cgs. unit of brightness, the brightness of a perfectly diffusing surface radiating or reflecting one lumen per square centimeter. This is equivalent to the brightness of a perfectly diffusing surface having a coefficient of reflection equal to unity and an illumination of one phot. For most purposes, the millilambert (0.001 lambert) is the preferable practical unit.

A perfectly diffusing surface emitting one lumen per square foot will have a brightness of 1.076 millilamberts.

Brightness expressed in candles per square centimeter may be reduced to lamberts by multiplying by $\pi = 3.14$.

Brightness expressed in candles per square inch may be reduced to foot-candle brightness by multiplying by the factor $144\,\pi = 452$.

Brightness expressed in candles per square inch may be reduced to lamberts by multiplying by $\pi/6.45 = 0.4868$.

In practice, no surface obeys exactly Lambert's cosine law of emission; hence the brightness of a surface in Lamberts is, in general, not numerically equal to its specific luminous radiation in lumens per square centimeter.

Defining equations:

$$L = \frac{dF}{dS}$$

or, when uniform,

$$L = \frac{F}{S}.$$

[3] In practice, the brightness b of a luminous surface or element thereof is observed, and not the normal brightness b_0. For surfaces for which the cosine law of emission holds, the quantities b and b_0 are equal.

17. Coefficient of reflection—the ratio of the total luminous flux reflected by a surface to the total luminous flux incident upon it. It is a simple numeric. The reflection from a surface may be regular, diffuse or mixed. In perfect regular reflection, all of the flux is reflected from the surface at an angle of reflection equal to the angle of incidence. In perfect diffuse reflection the flux is reflected from the surface in all directions in accordance with Lambert's cosine law. In most practical cases there is a superposition of regular and diffuse reflection.

18. Coefficient of regular reflection is the ratio of the luminous flux reflected regularly to the total incident flux.

19. Coefficient of diffuse reflection is the ratio of the luminous flux reflected diffusely to the total incident flux.

Defining equation:

Let m be the coefficient of reflection (regular or diffuse).

Then, for any given portion of the surface,

$$m = \frac{E'}{E}.$$

20. Lamp—a generic term for an artificial source of light

21. Primary luminous standard—a recognized standard luminous source reproducible from specifications.

22. Representative luminous standard—a standard of luminous intensity adopted as the authoritative custodian of the accepted value of the unit.

23. Reference standard—a standard calibrated in terms of the unit from either a primary or representative standard and used for the calibration of working standards.

24. Working standard—any standardized luminous source for daily use in photometry.

25. Comparison lamp—a lamp of constant but not necessarily known candlepower against which a working standard and test lamps are successively compared in a photometer.

26. Test lamp, in a photometer—a lamp to be tested.

27. Performance curve—a curve representing the behavior of a lamp in any particular (candlepower, consumption, etc.) at different periods during its life.

28. Characteristic curve—a curve expressing a relation between

two variable properties of a luminous source, as candlepower and volts, candlepower and rate of fuel consumption, etc.

29. **Horizontal distribution curve**—a polar curve representing the luminous intensity of a lamp, or lighting unit, in a plane perpendicular to the axis of the unit, and with the unit at the origin.

30. **Vertical distribution curve**—a polar curve representing the luminous intensity of a lamp, or lighting unit, in a plane passing through the axis of the unit and with the unit at the origin. Unless otherwise specified, a vertical distribution curve is assumed to be an average vertical distribution curve, such as may in many cases be obtained by rotating the unit about its axis, and measuring the average intensities at the different elevations. It is recommended that in vertical distribution curves, angles of elevation shall be counted positively from the nadir as zero, to the zenith as 180°. In the case of incandescent lamps, it is assumed that the vertical distribution curve is taken with the tip downward.

31. **Mean horizontal candlepower** of a lamp—the average candlepower in the horizontal plane passing through the luminous center of the lamp.

It is here assumed that the lamp (or other light source) is mounted in the usual manner, or, as in the case of an incandescent lamp, with its axis of symmetry vertical.

32. **Mean spherical candlepower** of a lamp—the average candlepower of a lamp in all directions in space. It is equal to the total luminous flux of the lamp in lumens divided by 4π.

33. **Mean hemispherical candlepower** of a lamp (upper or lower)—the average candlepower of a lamp in the hemisphere considered. It is equal to the total luminous flux emitted by the lamp in that hemisphere divided by 2π.

34. **Mean zonal candlepower** of a lamp—the average candlepower of a lamp over the given zone. It is equal to the total luminous flux emitted by the lamp in that zone divided by the solid angle of the zone.

35. **Spherical reduction factor** of a lamp—the ratio of the mean spherical to the mean horizontal candlepower of the lamp.[4]

[4] In the case of a uniform point-source, this factor would be unity, and for a straight cylindrical filament obeying the cosine law it would be $\pi/4$.

36. Photometric tests in which the results are stated in candlepower should be made at such a distance from the source of light that the latter may be regarded as practically a point. Where tests are made in the measurement of lamps with reflectors, or other accessories at distances such that the inverse square law does not apply, the results should always be given as "apparent candlepower" at the distance employed, which distance should always be specifically stated.

The output of all illuminants should be expressed in lumens.

37. Illuminants should be rated upon a lumen basis instead of a candlepower basis.

38. The specific output of electric lamps should be stated in terms of lumens per watt and the specific output of illuminants depending upon combustion should be stated in lumens per British thermal unit per hour. The use of the term "efficiency" in this connection should be discouraged.

When auxiliary devices are necessarily employed in circuit with a lamp, the input should be taken to include both that in the lamp and that in the auxiliary devices. For example, the watts lost in the ballast resistance of an arc lamp are properly chargeable to the lamp.

39. The specific consumption of an electric lamp is its watt consumption per lumen. "Watts per candle" is a term used commercially in connection with electric incandescent lamps, and denotes watts per mean horizontal candle.

40. Life tests—Electric incandescent lamps of a given type may be assumed to operate under comparable conditions only when their lumens per watt consumed are the same. Life test results, in order to be compared must be either conducted under, or reduced to, comparable conditions of operation.

41. In comparing different luminous sources, not only should their candlepower be compared, but also their relative form, brightness, distribution of illumination and character of light.

42. Lamp Accessories.—A **reflector** is an appliance the chief use of which is to redirect the luminous flux of a lamp in a desired direction or directions.

43. A **shade** is an appliance the chief use of which is to diminish or to interrupt the flux of a lamp in certain directions where

such flux is not desirable. The function of a shade is commonly combined with that of a reflector.

44. A globe is an enclosing appliance of clear or diffusing material the chief use of which is either to protect the lamp or to diffuse its light.

45. Photometric Units and Abbreviations.

Photometric quantity	Name of unit	Symbols and defining equations	Abbreviation for name of unit
1. Luminous flux	Lumen	F. Ψ	l
2. Luminous intensity	Candle	$I = \frac{dF}{d\omega}, \Gamma = \frac{d\Psi}{d\omega}$	cp.
3. Illumination	Phot, foot-candle, lux	$E = \frac{dF}{dS} = \frac{I}{r^2} \cos \theta . \beta$	ph. fc.
4. Exposure	Phot-second Micro phot-second	Et	phs. μphs.
5. Brightness	Apparent candle per sq.cm. Apparent candle per sq.in.	$b = \frac{dI}{dS \cos \theta}$	—
	Lambert	$L = \frac{dF}{dS}$	—
6. Normal brightness	Candles per sq.cm. Candles per sq.in.	$b_0 = \frac{dI}{dS}$	—
7. Specific luminous radiation	Lumens per sq.cm. Lumens per sq.in.	$E' = \pi b_0, \beta'$	—
8. Coefficient of reflection	—	$m = \frac{E'}{E}$	—

9. Mean spherical candlepower scp.
10. Mean lower hemispherical candlepower lcp.
11. Mean upper hemispherical candlepower ucp.
12. Mean zonal candlepower zcp.
13. Mean horizontal candlepower mhcp.
14. 1 lumen is emitted by 0.07958 spherical candlepower.
15. 1 spherical candlepower emits 12.57 lumens.
16. 1 lux = 1 lumen incident per square meter = 0.0001 phot = 0.1 milliphot.
17. 1 phot = 1 lumen incident per square centimeter = 10,000 lux = 1,000 milliphots = 1,000,000 microphots.
18. 1 milliphot = 0.001 phot = 0.929 foot-candle.
19. 1 foot-candle = 1 lumen incident per square foot = 1.076 milliphots = 10.76 lux.
20. 1 lambert = 1 lumen emitted per square centimeter of a perfectly diffusing surface.
21. 1 millilambert = 0.001 lambert.

22. 1 lumen, emitted, per square foot* = 1.076 millilamberts.
23. 1 millilambert = 0.929 lumen, emitted, per square foot.*
24. 1 lambert = 0.3183 candle per square centimeter = 2.054 candles per square inch.
25. 1 candle per square centimeter = 3.1416 lamberts.
26. 1 candle per square inch = 0.4868 lambert = 486.8 millilamberts.

* Perfect diffusion assumed.

46. Symbols.—In view of the fact that the symbols heretofore proposed by his committee conflict in some cases with symbols adopted for electric units by the International Electrotechnical Commission, it is proposed that where the possibility of any confusion exists in the use of electrical and photometrical symbols, an alternative system of symbols for photometrical quantities should be employed. These should be derived exclusively from the Greek alphabet, for instance:

Luminous intensity	Γ
Luminous flux	Ψ
Illumination	β.

DISCUSSION.

C. H. SHARP: In this report the stimulus coefficient is given the name *visibility*. The term is much shorter and has a great many advantages, so that we can speak of the visibility of radiation of any particular wave-length, which is the ratio of a luminous flux to the radiant power which produces it. There is a paragraph which has been inserted regarding the point source of light: "Strictly speaking, no point source exists, but any source of dimensions which are negligibly small by comparison with the distance at which it is observed may be treated as a point source." On the next page there are certain recommendations. "Milliphot" is recommended for scientific records of illumination. It differs by about 7 per cent. in value from the foot-candle and is based on the metric system. The "microphot second" is suggested as a convenient unit of exposure for photographic plates. On page 841 of the report, under Photometric Tests regarding the use of the term "apparent candlepower" is limited to the measurement of lamps with reflectors or other accessories at distances such that the inverse square law does not apply, where before the recommendation was more general than would be

justified. A new abbreviation has been introduced for mean horizontal candlepower, namely "mhcp."

F. A. Benford: I am glad to see that something has been done for our old friend the point source, but I think it should go one step further, because if you simply stop by saying that the distance must be larger in comparison with the dimensions of the source, you still get into trouble with the projection equipment; you cannot even faintly approach point source although the source of light may be very small, and I think some mention should be made of that in the definition. The critical distance in this case is from the source to the reflecting or refracting surface.

George A. Hoadley: Because this is a report of the Committee on Nomenclature and Standards, I feel that if possible we should avoid the introduction of any terms that would lead to a difference of opinion. In regard to this term "sensation of light," I am not at all convinced that light is a sensation. I believe sight is a sensation and that that is physiological. I believe that light could be defined in such a way as to avoid the use of this term "sensation," which brings up a difference of opinion or a misconception. It is just because we are defining it that I would like the definition to be made as clear and distinct as possible.

M. Luckiesh: I will take the matter up where Prof. Hoadley left off and repeat his objection to the use of light as sensation. Unquestionably we give two meanings to the word "light," and I would suggest that in the next issue of the Report of the Committee on Nomenclature and Standards, we give a definition of "light." Take any of the books on physics on the shelves to-day and you will find a good many different usages; three in general, of the word "light." Physicist used to speak of heat energy and light energy; other physicists who think of all this radiation, whether the eye sees it or not, whether it produces the sensation of light or not, speak of all radiation as energy, and some of us think of light as being a sensation entirely. I think we ought to standardize, in our report the meaning of the word light. I am strongly of the opinion that light is a sensation; and that is the most logical definition for it. In looking at the radiation curve, it is very easy to call one part the infra red region of the spectrum; it is very easy to call another part the visible region of

the spectrum; it is very easy to call still another part the ultra-violet region; and in no way do we need to apply the term light to radiant energy. This leaves the definition of light as a sensation, clear-cut. It seems to me unnecessary to use the word light for any radiant energy, whether we see it or not. Next, it is unnecessary to call the visible region light energy, because we can call that the visible region, compare it with the infra red region and the ultra-violet region and standardize the definition of the term light as a sensation.

LEONARD J. TROLAND: It appears to me, in connection with what Mr. Luckiesh said, that it may be possible to use the term light in such a way as to involve radiation, by considering light to be radiation multiplied by a certain factor, its visibility, so that when we speak of light, we imply both radiation and the luminous sensation. I would deem it a mistake to use the term light for the sensation alone, because in this case the properties of radiation would not be directly involved, and it seems to me legitimate to regard light as a conception having two factors, radiation and visibility. This is almost implied in certain definitions already given in the report of the Committee. I have said something concerning this problem in my paper, which I will read this afternoon.

DR. C. H. SHARP: As Secretary of the Committee during the past year, I have been very much pleased to notice the suggestions that have been made on the floor of the meeting and which cannot fail to be helpful to the Committee. I think that enough differences regarding the first definition have been developed right on this floor to show that the Committee had on its hands a problem of no small magnitude in formulating that definition. We have as the very first thing in the report, a definition of luminous flux, which is the quantity with which we have to deal in illuminating engineering, and it is defined as radiant power evaluated according to its visibility. We ignore the term "light" entirely. I think the suggestions should be brought up before the Committee when it is reorganized and meets again.

GAS ILLUMINATION OF THE PHILADELPHIA CIVIC EXPOSITION.*

BY C. S. SNYDER AND F. H. GILPIN.

Synopsis: This paper outlines the design, construction and installation features of the illumination for the Philadelphia Civic Exposition. Due to the large area to be illuminated and the unusual requirements for lighting the interior walls of the booths, there were developed many unique piping systems. The lamps and fixtures were designed to furnish a definite illumination at each booth and a uniform illumination over the area outside the booths.

An interesting installation of gas for illumination was in evidence from May 15 to June 10, 1916, when there was held in the Auditorium of the Philadelphia Commercial Museum an exposition to demonstrate the civic and public service activities of "To-day and To-morrow," of the city of Philadelphia. The building is a large one-story shed-like structure 295 ft. wide by 301 ft. long having three longitudinal center bays of 60 ft. span and 35 ft. clear height to the bottom chord of the roof truss and two outer bays of 25 ft. clear height. The outside walls are of brick painted light buff and the roof of weathered wood. Daylight illumination was obtained by numerous high narrow windows in the side walls.

The entire floor space of this area, though somewhat broken up by the pillars supporting the roof trusses, was divided more or less symmetrically into a large number of unit sections or booths for the exhibits. The partitions between sections were portable screens generally about 7½ ft. high by 10 or 12 ft. long, but in many cases several sections were combined by the removal of the intervening screens for the use of a single exhibition. In one small area, however, in the southwest portion of the room these partitions were 10 ft. high. There were also numerous exhibits of such a special nature that their height and all other dimensions were indefinite and variable. The general color of

* A paper presented at the tenth annual convention of the Illuminating Engineering Society, Philadelphia, Pa., Sept. 18-20, 1916.

all the screens was light buff. Although a few of the exhibits had special individual lighting by gas or electricity, the greater part of the area was illuminated by the main gas installation. The general lay-out is shown in Fig. 1.

After it had been decided that gas was to be used for the general illumination, calculations showed that the most satisfactory results would be obtainable by the use of a Welsbach No. 2076 lamp equipped with a No. 228 plain opal shade. Inasmuch as it required 320 such units, piping considerations (the supply lines being 35 ft. above the floor) necessitated the grouping of the lamps into eighty clusters of four lamps each. These clusters were arranged in ten longitudinal rows of eight clusters each spaced symmetrically with their mantle centers 20 ft. above the floor. One extra cluster of four lamps was placed over a balcony that was used as a bandstand.

DESCRIPTION OF PIPING AND METHOD OF INSTALLATION.

The installation of the piping system was a tedious and difficult undertaking, particularly so with the three center bays, in which the bottom chords of the roof trusses were 35 ft. clear height above the floor. The bottom chords of the trusses in the two outer bays were 25 ft. clear height above the floor.

The gas service was located at the north wall and very close to the center of the building. From this location the main feeding line was run south following alongside one of the roof trusses to which they were securely strapped and fastened. This main feeding line started with 4 in. pipe and was gradually reduced to 1½ in. pipe as the various branches were taken off. This main feeding line was run a little larger than necessary as there was some question whether or not gas would be needed for exhibition purposes in some of the booths.

Ten lines running east and west were taken off the main feeding line and outlets left so that the eighty drops were approximately 39 ft. apart, east and west, and 30 ft. apart, north and south. The roof trusses in the bays were 20 ft. between centers, and, therefore, the six lines in the high bays were run with 1½ in. pipe so as to reduce the tendency to sag. The ¾ in. drops

in these bays were approximately 13 ft. long and this piping together with the fittings and lights put quite a weight on the 1½ in. lines. The four lines in the outer bays were made of 1¼ in. pipe as the ¾ in. drops were only 3 ft. long.

All of the pipe between the various outlets was cut to length, screwed together and then hoisted to the top of the portable scaffold. Practically all of the piping rested on the top of the chords of the roof trusses so that there was no danger of any of the pipe dropping on account of loose straps, etc. The hardest work was experienced in running the main feeding line on account of the large size and the great height at which it had to be placed.

To aid in installing this piping system, there were constructed two large portable scaffolds, 32 ft. high, 6 ft. by 6 ft. at the bottom and tapering to 4 ft. by 4 ft. at the top. The four posts of the scaffold consisted of 4 in. by 4 in. lumber securely bolted and strapped together with 1 in. by 6 in. boards. On the top of each scaffold was a working platform 4 ft. by 4 ft. covered with 2 in. planking. Under each post was rigidly attached a heavy ball bearing castor. Similar scaffolds 22 ft. high were used for the outer bays. These portable scaffolds were easily moved about and it was not necessary for the men working on the platform to come down when the scaffold was being moved. Strips of wood were securely fastened to one of the posts, and this answered for a ladder.

At the bottom of each drop, a 5-way ¾ in. fitting was used, and the lights were hung 12 in. from the center of the drop.

All of the work with the exception of trimming a few lights was completed in five days. On account of the great amount of district work at this season of the year, it was not possible to force the work very much during the day, but at night from seven to twelve o'clock, the best men in the district were put on this work.

A gas meter capable of recording 3,400 cu. ft. of gas per hour was installed, and a 2 in. by-pass run around it, so that if anything happened to the meter the supply of gas would not be interrupted. On account of the short time available to complete the work, and as all the piping was exposed, it was not found practicable to test the piping with air as it was being installed. Great

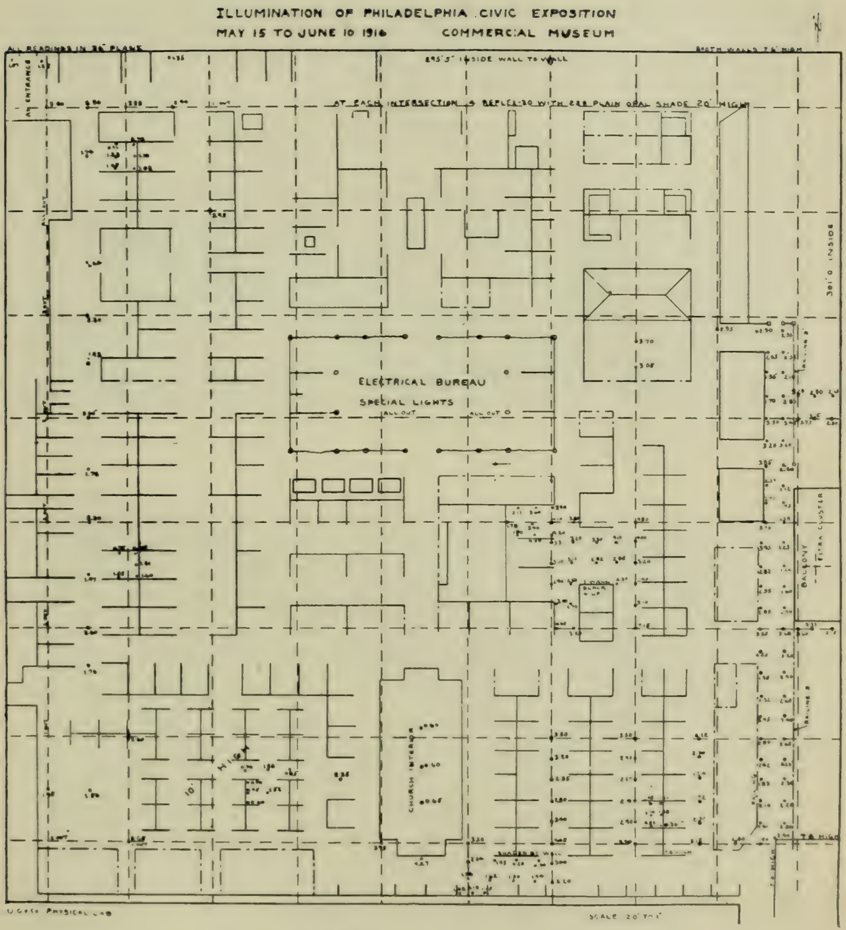


Fig. 1.—Plan of lighting—Philadelphia Civic Exposition.

Fig. 2.—Illumination of central passageway.

Fig. 3.—Illumination of part of the booth section.

care was taken however, to see that no split fittings or pipe were used and that all joints were made up tight. After all the lamps were hung, the gas was turned on and the system found practically tight. The chain on each lamp was lengthened 6 ft., so that they could easily be lighted or extinguished with a hook pole about 7 ft. long.

A remarkable feature of this installation was that in trimming 324 No. 2076 lamps, no leaks were found and no stoppages or defects encountered. At no time during the exposition were any of these lamps taken down on account of defects. This record speaks extremely well for the No. 2076 lamp. In making this installation no accidents occurred.

ILLUMINATION DATA.

The general appearance of the exhibition under artificial light is shown in Figs. 2 and 3. Fig. 2 is a view taken down the center of the entire length of the building and Fig. 3 shows a small section of one end. For the illumination measurements a plane 3 ft. from the floor was selected as representing the average height at which most of the exhibition lay-outs would be viewed. In addition the sides of each partition were completely covered with charts and photographs of the various articles which constituted a great part of the exhibition. Owing to the presence of the exhibits and partitions between the sections it was found practically impossible to lay-out any one section typical of the whole where a complete system of readings could be obtained without interference either by material obstruction on the floor or obstruction of the light by the partitions. Series of readings were, therefore, taken in various localities where the illumination appeared to be generally typical of the entire area. These readings are shown on Fig. 1. During the time of taking illumination measurements the average consumption per lamp as determined by the meter was 9.3 cu. ft. per hour representing for 320 lamps, 2,976 cu. ft. per hour for the entire area of 88, 795 sq. ft. or 29.8 sq. ft. per cubic foot of gas per hour (0.0336 cu. ft. per square foot area). By obtaining the mean of several similar representative unobstructed sets of observation points, the average illumination for the entire area was determined as 2.84 lumens per square foot or a total light flux of $2.84 \times 88,795 = 252,178$

lumens. Assuming 17.5×12.56 lumens per cubic foot available from the lamps, the total lumens emitted are $17.5 \times 12.56 \times 2{,}976 = 654{,}125$ lumens. This results in an utilization efficiency of 38.6 per cent.

One of the outstanding features of the installation is the uniformity of the lighting. To the eye it appears absolutely uniform, and the readings taken show that, except for spots when the direct light from the adjacent fixtures is entirely obstructed by the division screens, the minimum is over 30 per cent. of the maximum and 53 per cent. of the mean. The suspension height of the lamps removes practically all sources from the direct field of vision with the result that the entire area appears to be very brilliantly lighted.

DISCUSSION.

R. ff. Pierce: I would like to inquire as to the considerations which lead to the adoption of flat shades for the equipment of these lamps. From the figures of utilization efficiency, it appears to be rather low and I do not see any particular reason for using a flat reflector of this character where there is no necessity for illuminating side walls or ceilings. I would like to know the considerations which lead to the adoption of a reflector of that type rather than a more efficient deep bowl type?

F. H. Gilpin: The installation was originally designed to have a deeper reflector, but a type with a wider distribution was finally adopted to obtain greater intensity on the vertical partition walls.

THE EDUCATIONAL ASPECTS OF ILLUMINATING ENGINEERING.* †

BY F. K. RICHTMYER.

Synopsis: Engineering education, as we know it to-day, is a product of the past fifty years—much of it of the past thirty years. Illuminating engineering is unique in that the I. E. S. has taken the initiative in developing educational facilities in the technical schools. The I. E. S. has two more or less distinct lines of activities: (1) The development of the technology of illumination and (2) the education of the public to the importance of the subject of good lighting. The present status of educational work in each of these directions is discussed. There are appended extracts from the report of the 1913-14 Committee on Education giving proposed outlines of a four-year course in Illuminating Engineering, of a one-year graduate course in Illuminating Engineering, and of an adjunct course in illumination to accompany a regular course in Electrical Engineering.

A survey of the present status of the educational work of the Illuminating Engineering Society may with profit, be prefaced by a brief account of the rise of engineering education during the nineteenth century.

In view of the momentus part played, perhaps unwittingly, by the engineer in the present great war, it is not without interest to recall that the first engineering school on record, L'Ecole Polytechnique in France, was established in 1794 to train men for the artillery and for the engineering corps of the army. This country was not far behind, for eight years later, *i. e.,* in 1802, was founded the United States military academy, which, for a quarter of a century was the only organized agency in America for giving instruction in engineering, although it is said that many of the graduates of this school practised engineering in civil life.

Those who know the engineering of to-day, with its greater emphasis, in America at least, on the needs of civil life may find

* A paper read at a meeting of the Philadelphia Section of the Illuminating Engineering Society, May 19, 1916.

† I should like to take this opportunity to express to my colleagues on the Committee on Education, and in particular to Mr. Preston S. Millar, chairman of the 1913-14 Committee, my appreciation of the value of their services in preparing the reports upon which this paper is in large part based.

it difficult to believe that the schools of a century ago gave instruction only in military engineering. It was however in keeping with the development of the times. While it is perhaps impossible to say when engineering began, it is true that up to the middle of the 18th century the engineer was a military engineer. Beginning at that time, there gradually developed a group of professional men who devoted their attentions to other than military affairs. They were called civil engineers.

To America falls the premier honor of having been the first to establish a school for giving instruction in engineering for other than military purposes. This school was the Rensselaer Polytechnic Institute founded at Troy, N. Y. in 1825. Up to the close of the Civil War, this institution with two or three others founded later furnished the only facilities for obtaining an engineering education in America.

In 1862 occurred an event of the greatest importance in the development of engineering education in America—namely, the passage, by Congress, of the Morrill Land Grant, which gave to each state public lands, the proceeds from the sale of which were to be used for the benefit of "instruction in the arts and sciences relating to agriculture and the mechanic arts." This act resulted eventually in the establishment of over sixty technical colleges, "fifty of which offer instruction in at least one branch of engineering."

From that time on our economic development, made possible in large part by engineering successes, caused an ever increasing demand for young engineers. The number of students in engineering colleges increased accordingly, especially with the development of electrical engineering. As engineering practise became more complex, divisions and branches from the old civil engineering were formed, so that the technical schools to keep abreast of the times found themselves giving instruction in civil engineering, mechanical, mining, marine, hydraulic, sanitary, electrical, chemical engineering and naval architecture. Whereas the early engineering school (up to 1860, say) devoted a large part of its time to the study of mathematics and fundamental science, the school of ten or fifteen years ago gave 10 per cent. of its time to English or foreign languages, 30 to 40 per cent. to mathematics

and fundamental science, and the remainder, over half, to technological studies.

As the practising engineer became more and more of a specialist, it was recognized that his training should be more and more fundamental and in consequence a decade or so ago, we note a tendency, which has since grown, to increase the amount of time spent in the study of mathematics, chemistry, physics and general engineering, and correspondingly to decrease the amount of instruction given in what one might call "technological specialization." For example, in some schools, some of the instruction in the minor branches of engineering was either dropped entirely or was transferred to a supplementary year of graduate work. It is to be noted that the development of illuminating engineering began at about this time.

It is impossible to analyze, or even to estimate, without extended treatment, the effect which the several engineering societies have had on the development of the engineering school, and its curriculum. Certain it is that each of the three major engineering societies has exerted a very great influence not only on the development of engineering science but, perhaps, indirectly, in the teaching of it as well. For example, it would be interesting to know how much of the material in our modern engineering text books had its origin directly or indirectly in engineering societies.

It should be pointed out, however, that the older engineering societies were to a large extent the logical result of the growth of an already established profession. Thus, the American Society of Mechanical Engineers was established in 1880, when there were, already, a number of schools giving instruction in mechanical engineering. The American Institute of Electrical Engineers was organized in 1884, when electrical science, although perhaps not widely taught in schools of engineering, was well under way. In fact, two of the three men largely responsible for the founding of the American Society of Mechanical Engineers were university professors. Teachers have always been prominent members of these societies.

The circumstances connected with the development of illuminating engineering differentiate it, to a certain extent, from the older engineering professions. It is of course true that previous

to 1906 a vast amount of work had been done in developing and improving artificial light sources. But the establishment of the I. E. S. in that year marks the beginning of the systematic study of the science and art of illumination. The Society was founded, not by a group of engineers engaged in the practise of an already well established profession, but by a group of men who recognized the need for a systematic technology, for uniting a number of diverse interests in developing this technology, and for spreading the gospel of good lighting in both scientific and popular circles. This was an ambitious program and the extent of its success can be indicated in no better way than by repeating what has been said before to the effect that the history of good lighting in America is largely a history of the Illuminating Engineering Society.

At present the work of the Society seems to present two phases sufficiently distinct that one might say that there exist two Societies which might be called respectively the "Illuminating Engineering Society" and "The Society for the Promotion of Good Lighting." To the former, belongs the work of the Committee on Nomenclature and Standards, of the Committee on Glare, the Committee on Progress, etc.; while to the latter might be assigned the Committee on Popular Lectures, the Committee on Lighting Legislation, and a part of the work of the Committee on School Lighting.

The Committee on Education is interested in both of these phases of the Society's activities: in the technology of the subject, in so far as the teaching of it in schools of engineering and architecture is concerned; and in the popularization of the subject in so far as the teaching of it for purposes of advancing the cause of good lighting is concerned. It may not be without interest to review briefly the work of the several committees on education in each of these directions. For simplicity of reference, I shall speak of the one as "instruction in illuminating engineering"; and of the other as "instruction in good lighting."

INSTRUCTION IN ILLUMINATING ENGINEERING.

The 1913-14 Committee on Education, under the able chairmanship of Mr. Preston S. Millar, sent out to a large number of representative technical schools and colleges personally signed

letters, asking for information and data in regard to the extent to which the subject of illuminating engineering was being taught. Replies were received from thirty-nine institutions. The following paragraph from the report of the committee for that year summarizes the results of this canvass:

> It is apparent from this (canvass) that the committee has not learned of any course in illuminating engineering which is of a character warranting an institution in granting an illuminating engineering degree. There are a few institutions which operate an adjunct course or an elective course of such a kind as to afford some special instruction in illuminating engineering to students who are taking electrical engineering. There are a few institutions which operate a post-graduate course in which a good deal of attention is accorded illuminating engineering. The bulk of the replies indicate that the only attention given to the subject is the usual instruction in light, in physics departments, and some instruction in regard to electric lamps, their characteristics, and the design of lighting installations, as a part of the course in electrical engineering.

Having investigated the *supply* of instruction in illuminating engineering, it seemed logical to see whether the supply was equal to the demand, and consequently last year (1914-15) the Committee sent out nearly two hundred letters to various representative manufacturers and industrial organizations, asking (1) for information in regard to the number of men now employed, whose work dealt more or less closely with illuminating engineering; and (2) whether graduates of courses in illuminating engineering, should such be established, would be in demand.

Without analyzing the replies in detail, it may be said that the thirty-six manufacturers and sixty-seven public service corporations who answered reported a total of 1,250 men whose work dealt more or less closely with the subject of illumination. Some companies included salesmen and commercial men, while others included only those engaged in laboratory work or in illuminating engineering problems and design. It is evident that the number of men making use of illuminating engineering principles is much larger than reported, while the number engaged in strictly illuminating engineering work is smaller than reported.

Further, while the demand for graduates of a four year course in illuminating engineering is comparatively limited (only the larger companies employing men to devote their time exclusively to the subject), letters received from many companies emphasize

the value to them of a more general knowledge of the principles of illuminating engineering on the part of the men they employ, as part of their general engineering training.

It seems, therefore, that in so far as the training of men to devote their entire time to Illuminating Engineering is concerned, the colleges are probably, in view of the limited demand, offering adequate facilities. Most engineering schools offer graduate work in some form or other. It is well known that graduate study and instruction is particularly free from the necessity of following routine courses. A student who takes a year or more of graduate work is at liberty to follow any specialty he wishes. About half his time will normally be spent in investigating some special problem. The remainder will consist in collateral reading, the taking of certain advanced courses, etc. The graduate student is in large part his own instructor. Further, it is to be remembered that the actual technical knowledge obtained by a student in any engineering school is of comparatively little importance as a part of his education. An engineering education, like any other professional education, consists largely in giving the student the viewpoint of the profession, in making him familiar with the sources of information, which, later, he can refer to in working out his problems, and in showing him the kind of things with which he will have to deal. Probably very few engineers are *specifically* trained for that particular branch of their profession, which, in very many cases largely through accident, they are later to follow. The student's real engineering education begins after he has graduated.

We may therefore view with some complacency the fact that few if any schools offer a course in illuminating engineering intended to give the student a complete technical training in the subject. If he is desirous of becoming an illuminating engineer, he can take a year of graduate work, using the college library and research equipment. The successful completion of almost any research problem in illumination will have pointed out to the observing student many of the fundamentals of the subject.

It is in part in recognition of this fact that the Committee on Education is this year planning to send out to the various technical schools and colleges a list of research problems suitable for graduate students with the double purpose of giving the student a

definite list of problems from which to make a selection, and, perhaps more important by the great diversity of the problems of bringing to the attention of the teachers in these schools, the wide scope of the science of illumination.

This diversity of fundamental principles is the one objection to assuming that the student, in a year of graduate work or its equivalent spent in a department of electrical engineering will get a general view of illuminating engineering, and correspondingly it is a good argument for the establishment of a thorough technical course in the subject. The radio-engineer, for example, finds that much, if not all of the fundamentals upon which the practise of his profession is built, is to be found in the various courses in mathematics, physics and general engineering that are either a part of his engineering curriculum or are open to him by election. Not so with the illuminating engineer. Much of the present instruction in illuminating engineering is given from the standpoint of the electrical engineering department, either as part (a few lectures or laboratory periods) of the regular course in electrical engineering, or as a separate course (3 or 4 hours per week for a term), which is usually not included as part of the regular curriculum but may be taken as an elective. While some of these elective courses are very excellent, the student in general has no opportunity anywhere in his course to become familiar with, or even to hear of the existence of, those phenomena of physiology and psychology, to say nothing of art, which to-day are recognized as being so important to the subject of illumination. In the opinion of the writer, there is need for a thorough course (say of 3 hours per week for one term) in the physiology and psychology of vision. Were this available, a student could in one year of graduate work get a reasonable training in the fundamentals of illuminating engineering.

Although there may possibly be no demand at the present time for a four-year undergraduate course in illuminating engineering, it might serve as an indication of the type of things which an illuminating engineer should know if a hypothetical four-year course were outlined. Such an outline was prepared, under the auspices of the 1913-14 Committee on Education, together with a hypothetical 1-year graduate course, and is herewith presented verbatim from the report of the Committee in Appendix A.

Of more immediate value, however, is Appendix B which gives a detailed outline of a proposed adjunct course in illumination, to cover two or three hours per week for one year, and to be given in connection with a regular 4-year course in general engineering. This outline likewise was prepared under the auspices of the 1913-14 Committee on Education and is copied verbatim from its report. It should be of assistance to engineering schools in meeting the present demand for men who should know something of illuminating engineering as a part of their general training.

INSTRUCTION IN GOOD LIGHTING.

It was early recognized that one of the most important activities for the Illuminating Engineering Society would be the education of the general public to take a larger interest in the question of good lighting. As a result of this movement we have had the illumination primer, various lectures, exhibits, etc. The Committee on Education is interested in this matter from the standpoint of instruction in the elementary schools, high schools, schools of domestic economy, and in all classes where facts concerning the hygienic phases of the lighting question can be advantageously presented.

It was partly to call attention to the necessity for better illumination, and partly to ascertain the present status of such instruction, that the Committee on Education last year (1914-15) sent out two questionnaires, one to about 200 school superintendents in various representative cities and towns throughout the United States, and the other to about 250 departments of domestic science in as many colleges. Replies were received from 48 high schools, and 56 departments of domestic science.

Summarizing the results of the canvass of public schools, it can be said that with a few notable exceptions there does not seem to be a general tendency on the part of high schools and grade schools to make special mention of the subject of good lighting. This condition is apparently due to two causes: (1) The subject matter upon which teachers in these schools could base their instruction has not found its way extensively into current text books, nor is it readily available to the teachers in any other form. But (2), more important, broad as has been the movement for better lighting, it has not yet become sufficiently

widespread to have created on the part of pupils, or their parents, a demand that the children be given such instruction. So that, even were the teachers themselves alive to the situation, we must extend our efforts much further before instruction in good lighting is generally given, in adequate form, in the public schools.

The questionnaire asked for suggestions as to the most efficient methods of bringing about, through the medium of schools and school authorities, a larger appreciation on the part of the public of the importance of good lighting. The following are abstracts of some of the replies:

Give public lectures on the subject.

Interest the teachers in science.

Give proper attention to the subject in classes in hygiene. Many schools are still badly lighted. Architects seem to be more interested in supplying chandeliers, than in arranging for good lighting. Lighting methods have changed so rapidly that it is impossible for the public to keep pace.

Provide general instruction at intervals from the first grade to the end of the high school.

Would give lectures if material were available.

Build well lighted schools. (Three replies.)

Provide adequate text book treatment.

Suitable material, put in simple form.

However, of the 48 replies received, 30 made no suggestions in this direction.

As a result of this canvass the committee this year is making a careful study of the question. An analysis of the subject matter as found in current text books is being made, and if conditions seem to warrant, an outline of material, suitable for serving as a basis for giving instruction in good lighting in the public schools will be made.

A much greater interest in the subject of good lighting was found among schools of domestic science. Teachers in these schools say that they would be glad to give more instruction in the subject were there available suitable material in a form which could be used efficiently by the various instructors. Some attention is now being paid to the subject. In some schools or institutions where there is an academic department, the professor of physics, or in some cases the professor of electrical engineering, gives a few lectures. In others, the work is given by mem-

bers of the staff of the domestic science department, in connection with such courses as household architecture; hygiene and sanitation; art, decoration, and furnishing; household management; general survey lectures, etc. In fact, only a few of the schools replying reported that no attention is being given to the subject. Its importance is universally recognized. Apparently the Illuminating Engineering Society will find here a very fruitful field for its endeavors to further the cause of good lighting. Graduates of schools of domestic science are in large part home makers. If they are adequately impressed with the importance of correct illumination, they will demand better lighting conditions, not only in their own homes, but in the schools which their children attend, in churches, in auditoriums, and in all public buildings.

The Committee on Education is attempting to assist these schools by preparing a suitable outline of material, as non-technical as is consistent with an adequate treatment of the subject, upon which instructors in departments of domestic science can base their work. This outline, when completed, will be forwarded to the schools from which replies were received last year.

It is hardly necessary to add that the Committee on Education will be very glad to receive suggestions from members of the Society, as to its work and also to cooperate with interested persons or other societies and associations in furthering the cause of good lighting. When we look at the ten volumes of the TRANSACTIONS of the Illuminating Engineering Society, we conclude that the Society has accomplished a vast amount of work. But when we see the present lighting conditions in some of our schools, auditoriums, churches,—yes, and in some oculist's offices, too—we realize that in the work that must be done we have only just made a beginning.

APPENDIX A.*

A FOUR YEARS' COURSE OF STUDY LEADING TO THE DEGREE "ILLUMINATING ENGINEER."

Before presenting the following curriculum, it seems desirable to give in brief some of the more important points, general and specific, which were kept in mind during the preparation of the outline. The several

* Extract from the report of the 1913-14 Committee on Education.

members of the committee must inevitably hold radically different opinions regarding some of the vital questions connected with the proposed course—if for no other reason than because each would have to meet conditions different from the other members were he to install such a course in his own university. To get at the meat of such a discussion as must result, opinions as to the feasibility of the points at issue must be accompanied by careful statements as to the reasons for such opinion. It must further be remembered that we are not dealing with a specific physical question to which only one answer exists, but with "a differential equation, capable of a great number of solutions, each one correct in itself."

General Considerations.

In outlining any new course in engineering at least three things must be kept in mind:

First, present conditions and tendencies in existing engineering schools;

Second, the qualifications which the practising engineer must have;

Third, his probable field of operation.

It is assumed that any proposed course in illuminating engineering would probably be established in connection with some school of engineering already in existence. In order that the introduction of any such new course be seriously considered by any university, not only must its general plan follow present tendencies in engineering education but it must utilize to the fullest extent possible existing courses of instruction. Recognizing the fact that a large majority of practising engineers to-day are not only specialists, but even authorities, each in his respective field, many engineering schools are making their courses to contain more and more of the fundamentals of a general engineering education, and less and less of specialization. For it is almost an educational axiom that the greater the degree to which the practitioner specializes, the broader must be his fundamental education. This is simply another way of saying that the professional man is more and more getting his real professional education in practise, and that the function of the so-called professional school is to lay the foundation upon which this professional training is to be built.

Recognizing this tendency, it therefore does not seem desirable to lay out a course of instruction intended to turn out illuminating engineers, ready to set up private offices, were there no other considerations of importance. But other reasons of a somewhat more practicable nature make it desirable to steer away from a highly specialized course. Financial difficulties would probably in a great majority of cases prevent the introduction of a new curriculum containing many courses requiring additional instructional facilities. So that it is highly desirable to use so far as is possible existing subjects in fundamental science and engineering *as now taught*, even though they may not exactly coincide with material with which an illuminating engineer should be familiar. For example, the course in "mechanical laboratory" as proposed for the junior year,

contains, as taught in most schools, some material which an illuminating engineer should know; much that he does not need. Yet to provide a special course would be highly undesirable; for after all, *how* the student studies is within limits quite as important as *what* he studies. The illuminating engineer who in his student days ran a complete test of a Corliss engine will bring to a new and difficult problem in illumination quite as much originality and ability as the student who laboriously studied out how some other knotty problem in illumination was solved by *some other* engineer. We want to teach our embryo engineers independence, not imitation.

As for new material, if it must be included, let it be of one of two kinds: either it should be such as could readily be given by present teachers, without excessive extra study and preparation, or it should be so new and radical that it must be given by a special teacher. For example, the course in "architectural principles," as proposed for the junior year, would be of the first class. It should be given from the architect's point of view, should present his problems—with only a few solutions—and should deal with illuminating engineering, only so much as is necessary for reasonable continuity. Any competent professor of architecture could give such a course without excessive effort on his part and with comparatively little interference with his regular work in his own department. But on the other hand the course on the "Design of Illumination Systems" for the senior year should be so specialized that a special teacher would be an absolute necessity; so that it could not be "hashed over" by a man whose *main* interest lies in other directions.

In addition to a thorough grounding in fundamental physical science and engineering, the *practising* illuminating engineer should know, *among other things,* (*a*) the theory and practise of the central station, both gas and electric; (*b*) the theoretical basis of light production and measurement; (*c*) the theory and practise in the design of illumination systems, and accessories; (*d*) the fundamentals of the physiology and psychology of vision; (*e*) enough of architecture to be able to appreciate the architect's viewpoint and to use and interpret his working drawings. To these should be added, without doubt, many more items more or less important which will instantly occur to any engineer.

To cover all this material thoroughly would be hopeless; to skim over it all lightly would be useless. The obvious middle ground is therefore to do some of it thoroughly and to give of the rest only so much as is necessary to point out the various problems.

This middle course is the more obvious when we consider the field of operation of the illuminating engineer. Although the writer is not very familiar with practical illuminating engineering, yet it would seem that the more obvious places where the practising engineer will find his work are:

(1) As consulting illuminating engineer.

(2) As a specialist:
 (*a*) in the architect's office;
 (*b*) with fixture manufacturer (as designer of installations for customers);
 (*c*) with large central stations in various capacities.

(3) As research assistant or director in large laboratories.

(4) As specialist with or manager-owner of so-called "fixture stores," for the complete outfitting of lighting installations.

Obviously it would in general be impossible for the student to decide into which of these several fields he would ultimately find his life work. Hence the general preparation rather than the specific, since each field requires a special training to be obtained only through commercial experience.

THE CURRICULUM.

As to the specific problems to be met in actually arranging the course of study, the following items were kept in mind:

(*a*) The course as arranged should give the student opportunity for studying a few elective subjects ("general interest subjects" they are sometimes called) which may or may not have even an indirect connection with illuminating engineering. For this reason several electives are included at the expense of crowding out other desirable material. No further discussion of this provision seems necessary.

(*b*) It has been the writer's experience with students that intensive study over a short period is better than less intensive over a longer period. Thus a student gets more from four recitations per week during one term than from two recitations per week over two terms. This accounts for the apparent "bunching" of some of the courses.

(*c*) The sequence and arrangement of work has also been given special attention.

(*d*) For entrance to the course the same requirements are to be met as for entrance to any accepted course in engineering including advanced mathematics (*i. e.,* advanced algebra and trigonometry), three years of either French or German, Physics and Chemistry.

(*e*) No attempt has been made to suggest alternative courses or modifications as to hours or sequence. It is thought that best results would be secured by assuming that the course is actually to be used in some hypothetical university possessing an academic department and an engineering school. Should the outline, as finally modified by the committee, be employed as a basis for a course in illuminating engineering in any university, a competent director would of course make modifications to suit local needs.

The outline follows. In the first column is given the number of the course (for purposes of reference or discussion). The second column gives the title. In the third and fourth column is found, for the first term and second term respectively, the numbers of "hours credit" (or units) represented by the course, viz.: one recitation, or one lecture, or one three-hour drawing or laboratory period per week shall count one unit.

Course	Title	First term	Second term
	Freshman Year.		
1	Analytic Geometry, Differential and Integral Calculus	5	5
2	Elementary Inorganic Chemistry	6	0
3	Elementary Physics	0	6
4	Drawing and Descriptive Geometry	3	3
5	English	5	5
	Total	19	19
	Sophomore Year.		
6	Advanced Physics (Recitations)	5	0
7	Physics Laboratory	0	4
8	Chemistry (Qualitative and Quantitative Analysis)	5	0
9	Human Physiology	3	0
10	Psychology	0	3
11	Mechanics of Engineering	0	6
12	Shop Practise	2	2
13	Elective	3	3
	Total	18	18
	Junior Year.		
14	Electrical Machinery	4	4
15	Mechanical Laboratory	4	0
16	*The Physics of Light Production *The Chemistry of Light Sources	5	0
17	*Photometrical Measurements	4	4
19	Generation and Distribution of Gas	0	2
20	*Architectural Principles	0	2
21	*The Physiology and Psychology of Vision	0	4
22	Elective	2	2
	Total	19	18
	Senior Year.		
23	Generation and Distribution of Electricity	3	0
24	*Design of Illumination Systems	3	3
25	*Spectrophotometry and Radiometry	3	0
26	*General Lectures	1	1
27	Economics	2	2
28	Thesis	3	5
29	Elective	3	3
	Total	18	14

Total number of hours (or units)	144
Hours of *new* courses	30
Per cent. of new material in curriculum	21

* Indicates probable *new* courses.

DESCRIPTION OF COURSES.

For the sake of completeness the following brief description of each course is given This is of course not a complete outline for each course, but is simply an indication of the *kind* of subject matter taken up.

1. *Analytic Geometry, Differential and Integral Calculus.*—Five recitations per week for one year. Covers the usual elementary course in Analytic Geometry and Calculus.

2. *Elementary Inorganic Chemistry.*—Two lectures, one recitation, and three three-hour laboratory periods per week for one term.

3. *Elementary Physics.*—Four lectures and two laboratory periods per week for one term.

4. *Drawing and Descriptive Geometry.*—Three three-hour periods per week for one year. Intended to give the student proficiency in mechanical drawing and lettering, and a knowledge of working drawings, conventions, etc.

5. *English.*—Five hours per week throughout the year. A study of some representative works in English literature with special attention to composition, rhetoric, and grammar. (No statement as to the need of this course seems necessary.)

6. *Advanced Physics.*—Five recitations per week for one term. Includes mechanics, heat, electricity, magnetism, light, sound. Based on some standard college physics test.

7. *Physics Laboratory.*—Two two-and-one-half hour laboratory periods per week for one term on advanced laboratory practise with reports and collateral reading, special attention being paid to quantitative work and precision of measurement.

8. *Chemistry* (Qualitative and Quantitative Analysis).—Two lectures and three three-hour laboratory periods for one term.

9. *Human Physiology.*—General course occupying three lectures per week for one term.

10. *Psychology* (follows Course 9).—Three lectures per week for one term.

11. *Mechanics of Engineering.*—Six recitations per week for one term.

12. *Shop Practise.*—Two three-hour periods per week throughout the year. Use of hand and machine tools for wood working, pattern making, etc.; use of lathe, shaper, milling machine, etc., and study of various machine shop methods, including automatic machinery.

13. *Elective.*—Some fundamental science, such as botany, biology, or astronomy; or history, language, etc.

14. *Electrical Machinery.*—Four hours per term for two terms, in lectures, recitations and laboratory work. Covers the fundamental laws of electric and magnetic circuits as applied to electric machinery, together with a study in classroom and laboratory of motors, dynamos, transformers of both the direct and the alternating current type.

15. *Mechanical Laboratory.*—Two three-hour laboratory periods per week for one term. Strength of materials, forging, tempering, annealing,

calibration of instruments, heating value of coal, steam tests, efficiency tests, etc.

16. *The Physics of Light Production.*

17. *The Chemistry of Light Sources.*—Courses 16 and 17 form a combination which may be given: the first, three lectures per week; the second, two lectures per week throughout the term; or preferably, Course 16 five lectures per week until finished (say for three-fifths of the term), and Course 17 five lectures for the remainder.

16. Takes up the study of radiant energy, as to production, laws, and effects; a critical study, in part historical of the several light sources with such brief description of technical methods of manufacture as may seem pertinent.

17. A study of the chemical processes involved in light production, as for example the manufacture of the several gases used for illumination, chemical processes taking place in their combustion, effects of various ingredients and impurities, photo-chemical effects, etc.

18. *Photometrical Measurements.*—One lecture and two laboratory periods per week during the first term. Two laboratory periods per week for second term. With reports. A critical study of primary and secondary standards of light; accuracy of electric measuring instruments; precision and sensitivity and errors of various photometers and photometric methods, under different conditions; heterochromatic photometry; distribution and characteristic curves for various sources; illumination measurements both daylight and artificial; properties of reflecting surfaces.

19. *Generation and Distribution of Gas.*—One lecture and one laboratory period per week for one term. A continuation of Course 17. Theoretical and practical principles governing the generation, testing, and distribution of gases, standard commercial practise; laboratory experiments in gas manufacture and testing.

20. *Architectural Principles.*—One lecture and one drawing period per week for one term. Intended to present to the student some of the fundamental principles underlying architectural design and composition, together with a brief review of the several styles of architecture; familiarity with working drawings, office methods, etc.

21. *The Physiology and Psychology of Vision.*—Lectures and laboratory practise. Anatomy and optical properties of the eye; correction of errors of refraction; other ophthalmological tests; theories of vision; adaptation; fixation; color vision, color blindness, etc. Laboratory practise with ophthalmological apparatus, study of microscopic sections of eyes, appropriate experiments in psychological laboratory.

22. Optional elective (*i. e.*, may or may not be taken).

23. *Generation and Distribution of Electricity.*—Lectures on the selection of apparatus for generating and distributing systems; standard practise in design and arrangement; illustrated by problems.

24. *Design of Illumination Systems.*—One lecture and two three-hour drawing and computing periods per week for two terms. Design and use of illumination accessories (shades, globes, etc.); properties of the several

systems of illumination; conditions to be met in various exterior and interior installations; problems in design both daylight and artificial (architectural principles if Course 20 cannot be given).

25. *Spectrophotometry and Radiometry.*—One lecture and one laboratory period per week for one term with reports. Theory of spectrophotometric and radiometric measurements; detailed description of several fundamental instruments; laboratory practise with the spectrophotometer in determining luminosity curves; spectral energy distribution of several sources; absorption curves, etc.

26. *General Lectures.*—To be given, in part at least, by non-resident lecturers and to cover topics of general interest to the illuminating engineer, such as central station management, lamp manufacture, recent advances in light sources, special problems of an economic nature; research work in various fields, etc. Ten to fifteen lectures per term, not necessarily one each week.

27. *Economics.*—Covers such ground as is usually given in an elementary course, discussing practical considerations regarding the production and distribution of wealth.

28. *Thesis.*—Reading and studying the literature during the first term; experimental work second term. (Intended to give the student practise in studying the literature of his subject and in doing research work, rather than *to secure contributions to knowledge.* The pedagogical question involved here would be a very interesting theme for discussion.)

29. *Elective.*—Absolutely unrestricted.

A Special One-Year Graduate Course in Illuminating Engineering.

Many schools, who find it impossible to introduce a *four-year* course in illuminating engineering, for financial or other reasons, might consider offering a year of illuminating engineering as a special one-year graduate course following a general course in mechanical or electrical engineering. For such, the following selection of subjects from the preceding four-year course is suggested, suitable modification being made in such courses as 21 to cover fundamentals.

This special one-year course might also be offered by institutions giving the four-year course. No additional instruction would then be necessary.

Course	Title	First term	Second term
21	The Physiology and Psychology of Vision.....	4	0
18	Photometrical Measurements	6	2
16	The Physics of Light Production		
	The Chemistry of Light Sources..............	5	0
20	Architectural Principles	2	0
24	Design of Illumination Systems................	0	6
25	Spectrophotometry and Radiometry	0	3
26	General Lectures	0	2
28	Thesis	2	4
	Total	19	17

APPENDIX B.*

PROPOSED ADJUNCT COURSE IN ILLUMINATION.

In many educational institutions there has been in recent years a quickened interest in lighting methods and the problems arising in conjunction therewith, and to meet the demand for information along this line, many technical schools have desired and attempted to install a line of study in lighting and illumination as a required or elective adjunct to a regular four-year course in electrical engineering.

If one may judge from the material included in a number of books on the subject, there seems to be wide divergence of opinion among those charged with the administration of such study as to what should properly be included in an auxiliary course which must of necessity be confined to a scheduled time of two to four hours per week during a single year.

It must be recognized at the outset that with the prescribed time limitations, it is possible for the student to obtain little more than a knowledge of the character of problem to be solved and the general field covered by illuminating engineering; and also while unanimity of opinion as to the precise material and manner of treatment is not at all to be expected or even desired, nevertheless it seems that it should be possible to find some middle ground between authors (and teachers), one of whom allots of his book to light sources or illuminants, 0 per cent., to physiological aspects, 5.8 per cent., and to photometry and calculation, 67 per cent.; another to light sources, 32 per cent., physiological aspects, 5.7 per cent., and to photometrics and calculation, 32 per cent.; and a third to light sources, 15 per cent., physiological aspects, 0 per cent., photometry and calculation, 44.5 per cent. It is with the hope that the best thought of the Illuminating Engineering Society may be brought to bear upon this phase of the educational campaign to the end that some definite recommendations of the society may help to shape instructional work on illuminating engineering at a point where much the largest amount of teaching along this line is being done, that the following is offered. It is proposed not in any sense as a complete outline, but rather as a nucleus and as a basis for suggestion and criticism.

For purposes of comparison and as a basis for suggestion the material pertaining to illumination was divided, rationally, it was thought, into five main classes:

(1) Nature and Laws of Light.
(2) Sources of Light.
(3) Physiological and Psychological Aspects.
(4) Photometry and Calculation.
(5) Illumination Design and Engineering.

Under these heads material falling within the province of illuminating engineering as entitled in the Baltimore lectures is grouped.

* Extract from the report of the 1913-14 Committee on Education; prepared for the Committee by Prof. A. N. Topping.

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(1) Nature and Laws of Light.
  (*a*) Physics of Light Production.
  (*b*) Chemistry of Light Production.
  (*c*) Color.
  (*d*) Laws of Reflection.
(2) Light Sources.
  (*a*) Electric Illuminants.
  (*b*) Gas and Oil.
  (*c*) Gas Mantles.
  (*d*) Electric and Gas Lighting (manufacturing and distribution).
(3) Physiological and Psychological Aspects.
(4) Photometry and Calculation.
  (*a*) Units, Standards and Terminology.
  (*b*) Photometry.
  (*c*) Calculations.
(5) Illumination Design and Engineering.
  (*a*) Reflectors, etc.
  (*b*) Fixtures.
  (*c*) Architecture Considerations.
  (*d*) Exterior Illumination (design).
  (*e*) Interior Illumination (design).

The following is an analysis of four well known text books and the Johns Hopkins lecture course according to the foregoing classification:

TEXT BOOK ANALYSIS.

Book	Nature and laws Per cent.	Light sources Per cent.	Physiological psychological Per cent.	Photometric calculation Per cent.	Design and engineering Per cent.
No. 1	9.2	0.0	5.8	68.0	18.0
No. 2	6.3	32.0	5.7	42.0	14.0
No. 3	5.5	15.0	0.0	44.5	35.0
No. 4	35.5	13.5	9.0	20.8	21.2
Johns Hopkins Lectures	10.5	26.8	7.8	15.4	39.5
Proposed	17.0	23.0	10.0	20.0	30.0

An examination of the foregoing table and analysis will disclose the reason for the proposal of the outline attached. Three of four books devote 40 to 60 per cent. of their space to light measurement and the attendant calculations, which, considering the condensation of material due to mathematical forms and reasoning, represents somewhat more than the same percentage allotment of the student's time. It will be noted that the Johns Hopkins lectures devotes but 15.4 per cent. of its space to the same class. To light sources of illuminants, one author devotes 32 per cent. of his space; another ignores the subject. The Johns Hopkins lectures gives it 26.8 per cent. of its space. While most of the books examined give the physiological aspect of the subject from 6 to 10 per cent. of their space, one only ignores it entirely. To the design and engi-

neering phases of the subject, one author gives 14 per cent. of his space; another 35 per cent., and the Johns Hopkins lectures nearly 40 per cent.

It is recognized that engineering in general is based upon quantitative relations and that precise measurements and calculations are essential to engineering work and progress, but it is felt that in perusing certain books on illumination the student is apt to gain the idea that illuminating engineering is photometry and photometric calculation, whereas these are but details in a vast field of engineering work.

Instead of using large amounts of time in descriptive details of many pieces of photometric apparatus designed to do each the same thing, and in explanation of numerous methods of calculation to secure a given result, it is felt that much better results may be secured if such descriptions of photometric apparatus and explanations of methods are limited to one or two of the more useful and commonly used, and if the physical, physiological and engineering problems involved are presented with more emphasis and the student's interest quickened by what appears to him to be a live and growing subject.

With the foregoing considerations in mind the following more or less detailed outline is suggested in the hope that by processes of elimination and addition some definite conclusion may be reached.

OUTLINE OF A PROPOSED ADJUNCT COURSE IN ILLUMINATION.

	Per cent.	
(1) Nature and Laws of Light.		
(*a*) Nature and Forms of Radiant Energy	2	
(*b*) Laws of Temperature Radiation	5	
(*c*) Selective Radiation and Luminous Efficiency	3	
(*d*) Luminescence	2	
(*e*) Color—Its Physical Significance and Methods of Comparison	3	
(*f*) Laws of Reflection and Diffusion	2	
	——	17
(2) Light Sources.		
(*a*) Electric Incandescent.		
Historical Development	0.5	
Materials and Manufacture	2.0	
Physics and Chemistry of	2.0	
Operating Characteristics	4.0	
Economy and Adaptability	1.5	
	——	10
(*b*) Electric Arcs.		
Nature and Physical Characteristics	2	
Mechanism and Operating Characteristics	3	
Costs of Maintenance and Operation	1	
	——	6

(*c*) Gas Lighting.		
Chemistry of Gas Manufacture	1	
Incandescent Mantles	1	
Operating Characteristics	2	
Economy, Maintenance, etc.	2	
Gas Lamps and Equipment	1	
	——	7
(3) Physiological and Psychological Aspects.		
(*a*) The Eye—Its Structure and Functions	2	
(*b*) Effects of Radiation upon the Eye	2	
(*c*) Color		
Purkinje Effect	1.5	
(*d*) Visual Acuity		
Brightness	1.5	
(*e*) Glare	3	
	——	10
(4) Photometry and Calculations.		
(*a*) Notation and Units	1	
(*b*) Standards.		
Hefner, Pentane Lamp, etc.	1	
(*c*) Photometric Apparatus	3	
(*d*) Intensity and Flux Measurements	4	
(*e*) Illumination Measurements and Portable Apparatus	3	
(*f*) Illumination and Flux Calculations	8	
	——	20
(5) Illumination Design and Engineering.		
(*a*) General, Physiological and Esthetic Requirements	2	
(*b*) Reflectors, Shades and Fixtures	2	
(*c*) Interior Illumination.		
Intensities, Mounting, Location	3	
Control	2	
Selection of Systems and Apparatus	5	
Designs and Specifications for Actual Installations	6	
(*d*) Exterior Illumination.		
General Purpose and Requirements	1	
Location and Mounting	2	
Selection of Systems and Apparatus	4	
Designs and Specifications	3	
	——	30

Supplement to Outline of Adjunct Course in Illuminating Engineering.

It is suggested:

1. That this adjunct course may suitably be made part of the regular four-year course in electrical engineering;

2. That it should occupy not less than two, but preferably four or five lecture hours per week during one school year;

3. That it be administered as lectures, recitations and seminar in the senior year;

4. With the percentage allotment of time the division would be about as follows:

(1) Nature and Laws of Light...............	6 weeks
(2) Light Sources	8 weeks
(3) Physiological, etc.	4 weeks
(4) Photometry and Calculations	7 weeks
(5) Illumination Design and Engineering.....	11 weeks

DISCUSSION.

DR. H. E. IVES: It occurs to me that I can throw a bomb in the direction of the professors of electrical engineering who are present by saying that I do not believe illumination is a topic to be given in the engineering school at all. It is a branch of physics. It is applied physics. Illumination is very much more closely connected with optics—especially physical optics—than it is with engineering. I should like to see in our universities a kind of engineering preparatory course which might be called "applied physics." There is quite a gap now between the beautiful "it-was-all-done-by-Newton" physics which we find in text books and the practical applications which are of immediate interest to students, if brought to their attention. I talked the other day with a public school teacher of a movement now in progress to make the elementary instruction in science largely an exposition of practical applications. In that way science becomes more interesting to the student. The more interesting it is the more he wants to learn and the more he learns the more interesting it becomes—a kind of perpetual motion which is in accordance with good psychological principles.

My suggestion applies to the lament we hear that we cannot get lighting science before the architects. If such a course in immediate applications of science were a necessary preliminary to architectural study, as regular physics is now, the architect would at least know something of the fundamentals of lighting. As I have said before, it seems to me that what a man who goes into lighting most needs is the fundamentals of physical and physiological optics. But by the time a student has been three

years in an engineering school and has his attention chiefly directed to large scale engineering problems, such as the operation of large machinery and power distribution, he is largely out of touch with the eye and optical instruments and things of that sort which are touched on in his elementary physics. Perhaps, therefore, the way out is not to try to find courses which could be given in the engineering schools, but to go further back and consider some such thing as a required course in applied physics, part of which would include the fundamentals of the use of light for illumination.

Carl Hering: As this paper deals with educational features, I should like to again call attention to a matter that I have spoken of several times before at meetings of this Society, though little notice seems to have been taken of it; it concerns the simplification of what the students of illuminating engineering have to be taught. The simpler this subject is made to the student the more likely he will be to grasp it and become interested in it; I therefore wish to point out again some quite unnecessary complications in the units used in illumination problems. As an illustration, I might cite the following cases; I think it is now eight years ago that I mentioned it before and I may therefore be privileged to refer to it again.

Imagine three horizontal surfaces, of the same size, each issuing the same amount of light flux. Assume number one to be that of a molten metal, number two to be a piece of white paper illuminated with a searchlight, and number three to be a piece of milk glass illuminated from behind. To the eye they will be the same, as an illuminant; each will be a source of the same amount of light. Yet the way students are taught to-day, they have to measure number one with one kind of a unit, number two with another kind of a unit, and number three sometimes with one kind and sometimes with another.

Surely this is mixing up the student's mind, and quite unnecessarily. Here are three sources exactly alike as far as their light giving properties are concerned, yet he is taught to measure the first two in different units, and has to ask his professor which one of the two units to use in the third case, being probably told by him that when very bright he should use one kind of unit, while when dull, another. They ought all to be expressed and

measured in the same units, because they are all sources of light, and there is no justifiable reason to complicate matters for the student and get him all mixed up as to which units to use. This is merely one illustration of how the whole science of illumination could be simplified to the beginner.

I may add in this connection that the unit of brightness, namely, candles per square inch, is physically speaking an abortion as a unit. It is not a proper physical unit, because it is not rational; physically it is equivalent to measuring of the number of points on a square inch. Such a thing is inconceivable from the standpoint of physics, and yet we have been using that unit for about twenty years, I think.

Some eight years ago, before this Society and elsewhere, I showed how this irrational unit can always be transformed into the same unit as used for illumination, that is, foot-candles, by multiplying by a certain factor. It is therefore always possible to convert the former into the latter, and then it becomes a rational unit.

J. D. Lee, Jr.: Isn't the unit which is used for the measurement of the brightness of surfaces to-day the lambert? Isn't that the proper unit?

Carl Hering: That must be quite a new unit with which I am not yet familiar.

J. D. Lee, Jr.: The committee of the Illuminating Engineering Society having these matters in charge has taken up that question and they have considered the lambert as the unit of brightness, which can be converted into candles per square inch. Lumens per square centimeter is the lambert, as I understand it.

Carl Hering (Communicated later): I have looked up the reference to this new unit, the lambert, and find it was proposed (and apparently for the first time) in the report of our Committee on Nomenclature and Standards, last fall (see page 644 of our Transactions, No. 8, Vol. X, Nov, 20, 1915). This in my opinion is a step in the right direction, though I fail to see why that committee proposed it only for a surface "radiating or reflecting" one lumen per square centimeter and did not also include the third one of the three cases I mentioned above, namely, for transmitted light also; why should not the light from a milk glass globe, for instance, also be measured in this unit?

Their suggestion therefore does not go far enough; they should have included "transmitting" in their definition. And why still confuse the student by creating in his mind the wrong impression that what is generally referred to as "illumination" is so different from diffuse "reflection" that it must be measured in terms of an entirely different unit, foot-candles or luxes. An illuminated white wall is a source of light, though a secondary one, and as a source it would be quite the same as though it were a milk glass partition with a source behind it, or as if it were an original source say in the form of a phosphorescent surface (aside from the different natures of the surfaces themselves).

The original metric system is a good illustration to show how unnecessary units will in time be dropped by thinking people who have some regard for the conservation of mental energy. This original system included the "are" (surface) and the "stere" (volume), making five units to learn, together with their numerous suffixes and affixes. These have gradually dropped out of use (though not yet completely) because they were entirely unnecessary duplications of the square meter and the cubic meter. A third one of the original five, the liter, is another unnecessary one and will, I hope, also be dropped in time, as it is merely a volume unit which it is simpler to express in cubic centimeters or decimeters; the chemist is more progressive than others as he has dropped it long ago, stating all volumes in cubic centimeters, or its multiples. Hence two of these five original metric units—length and weight—are quite sufficient for all purposes, then why burden the student's mind with five, as mine was when I went to school. And why wait for the slow process of custom to bring about such an economy of mental energy, when it could be done at once? We laugh at the tender-heartedness of the kind lady who wanted her dog's tail cropped but, pitying him for the pain, she cut off an inch a day instead of doing it in one operation; yet she is what our descendants will liken us to in our cropping off the unnecessary units by numerous nibbles instead of in one bite. Meanwhile the student's mind and the practical engineer's work are unnecessarily burdened.

The student should also be taught that lumens and spherical candles are both measures of one and the same physical quantity, namely, amount of luminous flux, and that the best one to use in

any particular case is the one which saves introducing the exasperating factor 4π. Also that candlepower and foot-candles are physically both a flux density, differing only in that one is for convenience expressed in solid angular units and the other in surface units; both have their use, though physically the same quantity.

I notice that in the above mentioned report the committee has given the reduction factor 144π for converting candles per square inch to foot-candles, which when I first stated it eight years ago and urged its adoption, was apparently entirely ignored. Also that they have made a creditable attempt to alter the definition of the old and irrational unit of brightness so as to make it at least physically rational.

A complete analysis of the units of light, showing how simple their interrelations are, and how few would suffice in practice and in teaching the student, was given by me in a paper read before this Society in October, 1908, on "Calculating and Comparing Light from Various Sources," and published in these TRANSACTIONS, Vol. 3, November, 1908, p. 645.

T. ELMER MOON: I have been very much interested in that part of the paper which gives the practical difference in the course of illuminating engineering from the electrical engineering courses that are outlined in the average college prospectus. It hardly seems to me likely that a young man could put four years of study into one detailed course like that, and obtain it at one university. He would probably have to go outside to get his study of the eye—perhaps in a university like the University of Pennsylvania, he could study the various portions of the eye and how they function, in the medical school, but he could not get that in the engineering courses.

I am glad to be in the shadow of such a big tree as Dr. Hering, and agree as to his differences with Dr. Ives. It seems to me that in physics, the professor will give you the fundamentals, just as he gives you the fundamentals of magnetism and electricity; but it is in the engineering courses, where we take up the study of motors and motor applications, and we find that the various distributions of magnetic flux will give a certain torque, and learn to properly apply and supplement the basic knowledge

of our physics courses, that illumination belongs. I won't say that the physicist is incompetent to do this, but it is not his particular field. The application of illumination is certainly in the engineering school—if on an engineering basis—but, as brought out in this paper, illuminating engineering consists not only of chemistry, physics and mathematics, but also largely has to do with psychology and physiology; full instruction in these matters can only be brought about in a school which has departments in these branches.

I rather like the idea of the graduate course of illumination, except that the architectural principles should be given more time. That is a very great consideration. We are prone to think that the architect is very stupid when he does not understand us right off the reel, and no doubt he thinks the same thing about us when we do not understand his appreciation of artistic detail, and when he wants to get a certain result in light, and shade, and color effect he wants us to "get it." The laws of light are immutable, but we must lend ourselves to the esthetic as well as the application of physical principles. It is in recognition of these facts and to the man who has originality of ideas; who, as suggested in the paper, is not going to imitate, but is going to be broad enough to open new lines for himself, which will push illuminating engineering to the peak. This cannot be done by any strict adherence to what might be called the "Physics of Light." He must get that out of his imagination as well as various other things with which he comes in contact.

My studies of illumination have extended over a period of about six and one-half years, and I do not think I could take all the courses indicated, in one year, and get a proper cognizance of what would be required when I graduated. I think it would probably take two years. Of course that will be deliberated upon by those in authority. I think four years is too long. Illuminating engineering in its present status does not seem to warrant the making of a new course. The broad fundamental training as given in our colleges, permitting a man to specialize afterward, is, to my mind, the proper attitude. The graduate course of illuminating engineering, with the mass of data that the student must get in order to properly fit him to practice his profession,

will take more than one year, and this cannot be too much emphasized.

GEORGE A. HOADLEY: A number of years ago in connection with the work—particularly in electrical engineering—we began the teaching of a course that we called "illumination." We gave it in the second semester of the junior year. After the students had gotten the edges ground off sufficiently, so that they could understand the method of attacking certain definite problems, we took as a text some of the well known text books on illumination, and used that as a basis for our work. We took up the ordinary methods of illumination measurements by means of different forms of photometers, distribution of light, etc., and gave to it, in each week, one lecture period or recitation period, and a two-hour period of experiment. This, together with certain problems that were given for solving and bringing in results, was the extent to which the work was carried on. The work began in a simple way and grew as our opportunities and apparatus increased. I always felt that it was of value and have been assured of it from remarks that have been made by the young men who took the work at that time. It seems to me a most important adjunct and addition to the course in any kind of engineering.

Our engineering courses have differentiated themselves so much that it seems to me that we shall have to consider the question of a course in general engineering which shall embrace the principles of these different kinds of engineering and enable a man who is not specialized along any one particular line to do acceptable work along any line. The fact is that some of the best engineering work that has ever been done in the world has been done, not by men who have studied any particular branch of specialized engineering, but by men who are thoroughly versed in the fundamentals of science.

The applications that we have here are particularly along the line of physics, mechanical engineering and chemistry. It has always seemed to me that thorough basic information concerning those lines was actually of more importance than the specialization of work. Whether it will be possible to carry out a four years' course in illuminating engineering leading to a degree of that name is something that will need to be worked out in the future.

WALTON FORSTALL: In reading what Prof. Richtmyer has written on educating the public to a larger appreciation of the importance of good lighting, it occurred to me that more use could be made of the school children. Within recent years a number of high schools have been erected in Philadelphia, probably all of them without enough thought to their lighting. Would it be possible for the Illuminating Engineering Society to say to the Board of Education, "When you design the next high school, we should like a chance to advise you on the lighting." Perhaps you might find many reasons why this course could not be taken; but, again, some things which at the beginning appear impossible, are, after all, accomplished without too much trouble. I have spoken of high schools, though, of course, all schools should be considered.

JOHN R. HARE: I want to say that I believe that the time has arrived—perhaps it has long since passed—when the principles of correct lighting should be presented to school children in elementary text books, perhaps along the same lines as was done years ago, when the ill effects of narcotics and alcoholic drinks were presented.

It seems to me that the earlier in life that we can present the importance of a problem to anybody the more effectual results we get, if we properly present it. It occurs to me that illumination is as vitally important to a human being as the care of the teeth or any other organ of the body—some of which can be replaced in case of necessity, but we know that we cannot replace our eyes, or even repair any damage. There is now such a demand on the eye for intensive work that every effort should be made to conserve and protect it.

F. K. RICHTMYER (Communicated later): I cannot quite agree with Dr. Ives in his suggestion that illumination should not be taught in the engineering school. To be sure illumination is applied physics. But that is exactly what engineering is. The difficulty is that illumination is more than applied physics. It is applied physiological optics, applied psychology, and—if I may use the term in this peculiar sense—applied architecture. With the fundamentals of the *production* and *distribution* of light every well trained engineer should be familiar, at least in so far

as the *kind* of principles and processes involved. He has studied physics; he has studied chemistry; though probably not enough of either. It is when we come to the *consumption* of light that we find the difficulty. The engineer has *never* studied physiology, psychology, and art. However, so much of illumination *is* engineering that it would seem preferable to introduce these latter subjects into the engineering curriculum rather than to try to introduce physiology, psychology, art, and engineering into a course given by the physics department. It is simply a case of securing cooperative teaching among several groups of teachers not now accustomed to cooperate. But I heartily agree with Dr. Ives in his implied suggestion that illumination should not be taught *solely* from the standpoint of engineering.

I wish to point out further that, in the teaching of physics, there is quite as much danger in giving undue emphasis to the applications, developing the subject solely from this standpoint, as in teaching only the so-called classical physics. Either extreme is dangerous. It seems to me that the obvious course to be followed lies between these two extremes. The value of the teaching of physics to the engineering student comes partly from furnishing him with a certain few principles upon which his engineering is now based, and in giving him an appreciation of the extent to which *new* developments in physics may form the basis of *new* developments in engineering—a matter of primary interest to every progressive engineer.

Mr. Hering's suggestions regarding units can well be applied also to other branches of engineering and physics. There is nothing that promotes clear thinking quite so much as well defined and logically developed units. However, I believe that illuminating engineering is not behind other branches in this matter.

In regard to Mr. Moon's suggestion: Of course a satisfactory curriculum in illuminating engineering could not be compiled out of material already found in our engineering schools. It is to be assumed that any college of engineering which establishes such a course would introduce the necessary new subject matter either from other colleges of departments of the university, or by obtaining specialists for the purpose. The situation is not different from that which obtains at present in the growing tendency

to give engineering students a course in economics or business law.

Should the one-year graduate curriculum prove too long I should favor reducing the subject matter rather than extending the time. I do not believe the average graduate of an engineering course would look with favor upon spending *two* additional years in graduate study.

In closing may I thank the several members for the interest they have shown in this discussion. I believe that the practicing engineer should have a larger part in shaping the curriculum of the engineering school. The Illuminating Engineering Society, in thus giving some of its attention to pedagogical problems, is building securely for the future.

ABSTRACT OF PAPER—MODERN GAS EQUIPMENT FOR RESIDENCE LIGHTING.*

BY M. A. COMBS.

The progress in gas lighting in the last few years has been very great in all branches of lighting, but particularly marked is the development of residence lighting within the past year or so. Co-operation between fixture and burner and lamp manufacturers has resulted in improved fixtures, with increased efficiency in the burner. As an example, the horizontal burner has made possible the successful application of gas to semi-indirect lighting, opening a large field where gas lighting has every opportunity to demonstrate its great advantage of economy. Other signs of progress are the development of new lighting units, the constant improvement in mantles, the tendency to use only diffusing shades, and the new silk shades for gas lamps.

LAMPS AND FIXTURES.

The latest units are:

1. A new inverted lamp.
2. A lamp with upright burner and three inverted mantles.
3. The horizontal burner.

1. The new inverted lamp has an enamel stack finished in various colors, uses two sizes of mantles and has a single chain control, with improved pilot features.

2. The upright unit, which has three, small inverted mantles is especially adaptable for use on old fixtures without affecting their symmetry. It has rag mantles made of artificial cellulous fiber which can withstand rough usage.

3. The horizontal burner, about which the semi-indirect fixture is built, gives high efficiency and long life to the mantles and glassware. It is made in a variety of sizes.

The lamps and burners in common use for home lighting are as follows:

* Abstract of a paper presented at a meeting of the New York Section of the Illuminating Engineering Society, New York, December 8, 1915.

Lamp	Consumption	M.S.C.P.
Small upright mantle burner................	1.6	35
Upright burner, 3 small mantles............	3.0	70
Gallery burner, short mantle................	3.7	80
Gallery burner, long mantle................	4.5	100
Inverted lamp	2.0	50
Inverted lamp	2.5	60
4 inverted lamps	3.75	90
1-mantle, horizontal burner	1.5– 2.5	40– 65
2-mantle, horizontal burner	3.0– 5.0	75–110
3-mantle, horizontal burner	4.5– 7.0	115–160
4-mantle, horizontal burner	6.0– 9.0	150–200
5-mantle, horizontal burner	7.5–11.0	190–300

The range is from 35 to 300 mean spherical candlepower, with consumptions of 1.6 to 11.0 cubic feet per hour. All figures are for the mantles bare, or covered with clear glassware. The lamps and burners are all equipped with by-passes for pilot ignition.

Briefly, there are four sizes of upright burners for direct lighting, ceiling fixtures and wall brackets and portable lamps; three sizes of inverted lamps in common use, and a fourth and larger size which may be used; and five sizes of horizontal burners, each of which may be equipped with two sizes of mantles.

Ceiling fixtures and wall brackets for upright and inverted lights of high quality and great variety are to be obtained from all gas companies. Semi-indirect fixtures in all sizes, ranging from 10-in. to 30-in. bowls are supplied, and one form may be had having two, three or four small bowls clustered around a central supporting stem.

Semi-indirect fixtures are especially adaptable for combination lighting, where mantles and bulbs may both be used in the same bowl.

Local control is largely used in residence lighting, with pilot light and chain or key by-pass cock. Successful distant or push button control is obtained by using a magnet valve with pilot light or some other ignition device. Several dependable magnet valves are to be had, which are all supplied with pilot by-pass. Pilot ignition is in general use and has proven to be a most reliable gas lighting device.

A few samples of up-to-date lighting fixtures were shown on exhibit and illustrated, and then illustrations of actual installa-

tions were shown to give some idea of which is being accomplished by gas in good lighting throughout the home.

CONCLUSIONS.

In addition to the good appearance and practicability of gas for residence lighting, its advantages are:

Reliability.—No extended interruption of gas service has ever been known to occur.

Convenience.—Equal to any other type of illumination.

Color.—Approximate white, which is the best base to start from, as any color may be obtained by suitable shading. Low intrinsic brilliancy practically eliminates glare, especially so as mantle is almost always protected by diffusing glassware.

The satisfactory service rendered by modern installations shows that gas lighting needs no champion but itself.

PROGRESS IN STORE FRONT LIGHTING WITH GAS.*

BY CHARLES IRVING HODGSON.

Outdoor gas arc lighting service is now being supplied in a manner that meets the demand for modern and efficient illumination of store fronts. The principal features of the equipment and service are well made lamps, ornamental brackets, electric valve control and a ten-day interval of maintenance.

The lamp used is of the inverted type (Fig. 1), three or five-mantle, equipped with either clear or opal glass globe and a steel enamel reflector. The brackets are extended to bring the lamps between 3 and 4 ft. from the face of the building. The mounting height is governed by the height of the windows or doorway of the store front to be lighted. The most symmetrical arrangement brings the horizontal part of the bracket on a line with the top of the window. This practice has resulted in bringing the lamps 9 to 12 ft. from the sidewalk, which gives a fair proportion of light into windows and entrance ways and at the same time provides excellent sidewalk illumination.

For remote control of the lamp an electric valve (Fig. 2) is chosen which has met the most severe requirements. This valve is fitted to the side of the lamp, displacing the regular hand-operated valve furnished by the lamp manufacturer. The actual shutting off of the gas is controlled by a metal button attached to the center of a flexible sheet metal diaphragm. This metal button can be brought into contact with an accurately machined ring-like seat having a minimum of bearing surface, practically a knife edge; thus absolutely preventing the passage of gas between the two parts and preventing the sticking together of these parts.

No more cells of battery should be used than are actually necessary to operate the valves, and when the latter are properly connected, it has been found that one cell of battery will operate several valves, providing the distance from the battery and push button to the valves is not excessive. The size of control wire used must be properly chosen for a given installation and careful

* A paper presented at a meeting of the Philadelphia Section of the Illuminating Engineering Society, Philadelphia, Pa., Dec. 8, 1915.

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attention given to soldered joints and connections to binding posts.

No part of the electric circuit can be reached by the gas, and none of the moving parts of the magnetic circuit is exposed to gas. There is, therefore, little chance for sticking due to burning or corrosion and no reduction in the speed of operation. The amount of current required by the magnetizing coil is approximately 0.51 ampere. The corresponding current required for the demagnetizing coil is approximately 0.15 ampere.

The lamp brackets available from the manufacturers were not readily adapted to the different piping conditions, so it was finally decided to standardize the pipe size to be used on the outside for lamp work and at the same time adopt a set of 90-deg. and 45-deg. fittings, with which could be modeled brackets having a uniform and decorative appearance. With these fittings a great variety of brackets can be made which are readily adapted to any piping condition. Fig. 1 illustrates four distinctive types.

The fittings consist of 45-deg. and 90-deg. crosses, tees, slip tees and flanges. In addition to these is a gas-tight adjustable coupling which can be adjusted to any desired angle and an ornamental acorn cap. Another fitting which has great value is a 45-deg. flange elbow in one piece; this is used when the supply comes through the frame of the window and a secure fastening is desired for a lamp hanging in front and close to the glass.

Several gas sign-board installations have been made and no difficulty was experienced in installation or maintenance. Fig. 3 illustrates a sign-board on top of a building, running along the front and side edges of a flat roof; bottom of board being 35 ft. from the ground. The front sign is approximately 19 ft. long and 10 ft. high; the side sign is 60 ft. long. The lamps extend 4 ft. out from the face of the sign and the bottom of the globe is 1 ft. above the top of the board. The lamps are of standard three-mantle design equipped with clear globe, parabolic reflector and magnetic valve. The brackets are equipped with a universal swing at top and bottom and by releasing one guy wire can be swung to the rear of the sign for cleaning glassware and replacing mantles. There is no element of hazard in doing this work as an ordinary 8-ft. ladder may be used on the flat roof.

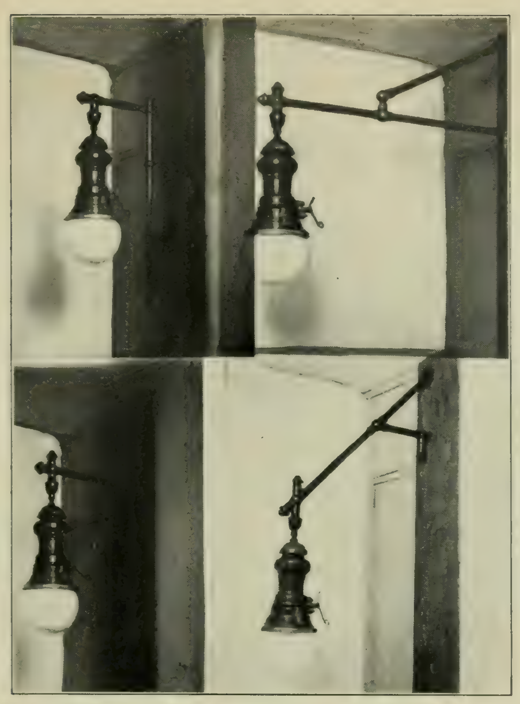

Fig. 1.—Type of lamp and brackets for store front lighting.

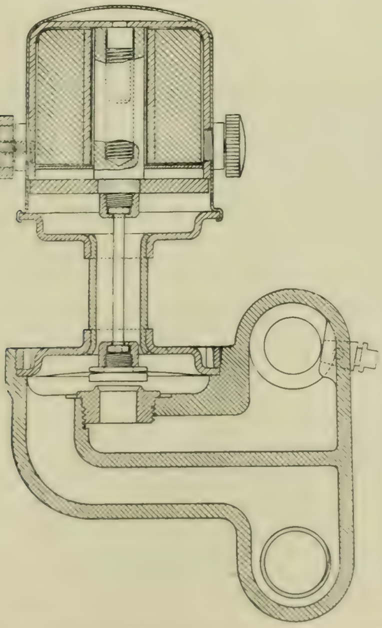

Fig. 2.—Electric valve for remote control of the gas lamp.

Fig. 3.—Sign boards illuminated by gas lamps.

Fig. 4.—Front of a ware-room illuminated by gas lamps.

The lamps are extinguished by means of a clock momentarily closing the extinguishing circuit. Fig. 4 shows bracket installations of outdoor gas lamps in front of a large furniture wareroom.

The necessity of adequate maintenance becomes apparent when one considers the conditions under which the lamp operates. The number of maintenance calls should be governed by local conditions—a ten-day period generally results satisfactorily. High grade material in the way of mantles and glassware are essential. Inspection of each lamp trimmer's work is also necessary. This is taken care of by an inspector for each fifteen trimmers. Record sheets are kept in such detail that it is possible to compare individual maintenance costs, thus aiding the inspector in keeping close check on all classes of material used and other items of expense.

CONCLUSIONS.

The sale of an outdoor gas lamp is of no lasting benefit to the gas company unless accompanied by service.

This service should consist of a pleasing, permanent installation, some form of convenient distant control, and thorough, efficient maintenance properly supervised.

The Brooklyn Union Gas Company has endeavored to fulfil all these requirements, in the installations in the city of Brooklyn

THE LUMINOUS EFFICIENCY OF THE SOLAR RADIATION.

BY HERBERT E. IVES.

In Vol. XI, No. 3 (May, 1, 1916) of the TRANSACTIONS, Mr. H. H. Kimball gives some interesting and valuable results of measurements on the illumination produced by sun and skylight, together with simultaneous measurements on the total radiation. By combining the two kinds of measurements one arrives at a figure of considerable interest, namely, the *luminous efficiency* of the solar radiation at the earth's surface. This is actually what is given in the ratio used by Kimball to express his results, namely

$$\frac{\text{Solar illumination in foot-candles}}{\text{Solar radiation in gram calories per min. per sq. cm.}} \qquad (1)$$

Due, however, to the several different systems of units employed, the final figures (roughly 4,000 to 10,000), convey little to minds accustomed to think of luminous efficiencies in lumens per watt, or better still in the direct percentage given by the ratio

$$\frac{\text{Luminous flux}}{\text{Total radiation flux}} \qquad (2)$$

both being expressed in the same units, *e. g.*, watts.

The reduction of Kimball's values is immediate upon noting that

1 foot-candle = 0.001076 lumen per sq. cm.
1 gram calorie per minute = 0.0697 watt

so that his figure is to be multiplied by the ratio of these or

$$0.01545 \qquad (3)$$

to give lumens per watt. Upon multiplying this last figure by the mechanical equivalent of light (0.00159 watt per lumen),[1] the multiplier to give absolute efficiencies (watts of luminous flux per watt of radiation) is obtained, namely,

$$0.0000246 \qquad (4)$$

In the following table are given figures from the paper referred to, recalculated in the more familiar and preferable units:

TABLE I.

	Ratio (1)	Ratio (1) × (3) (Lumens per watt)	Ratio (1) × (4) (Luminous efficiency)
Solar zenith distance 48.3°	5,600	86.5	0.138
Solar zenith distance 66.5°	5,100	78.9	0.125
Solar zenith distance 73.5°	4,600	71.1	0.113
Diffuse sky radiation......	8,900	137.3	0.218
Overcast sky	6,250	96.5	0.154

It is interesting to note that the value for the highest position of the sun (13.8 per cent.) is almost exactly that calculated by Kingsbury[2] for the maximum efficiency of the black body, which occurs at 6,500 deg. absolute. This does not mean that these figures give an independent estimate of solar temperature, for both infra-red and visible regions are much reduced by absorption and scattering. It should, however, be possible by extrapolation to arrive at a figure for zero thickness of atmosphere, and thus to one variety of "black body temperature" of the sun.

The primary object of the present note is to derive, from the data given, the hitherto unknown value of the luminous efficiency of the solar radiation. At the same time it offers an opportunity to demonstrate the great simplicity introduced into illumination calculations by the definitions and quantities recommended by the writer recently in the TRANSACTIONS.[3] Thus the efficiencies given in the last column of the table are those which would be found if the ratio were obtained of the solar radiation through a "visual luminosity" filter to that without a filter. At the same time they are the luminous efficiencies on that scale in which the most efficient possible radiation for visual purposes is of unit luminous efficiency.

It should not be overlooked that Kimball's values are all in terms of the calibration of his color difference eliminating blue glass screens. This calibration may not be in exact agreement with the photometric scale by which the mechanical equivalent of light was determined, thus introducing some uncertainty in column (3). This is a point which can only be satisfactorily settled after the official adoption of a definite photometric procedure and scale. This uncertainty is not nearly so great as the range of

variation of the ratio in question with different atmospheric conditions.

NOTES.

1. A full discussion of the subject of luminous efficiency is given in the *Journal of the Franklin Institute,* October, 1915, p. 409.
2. Kingsbury, *Physical Review,* February, 1916, p. 161.
3. Ives, TRANS. I. E. S., June, 1915, p. 315.

ABSTRACT OF PAPER—WORK OF THE LIGHTING SERVICE DEPARTMENT OF THE PHILADELPHIA ELECTRIC COMPANY.*

BY G. B. REGAR.

The work of the Lighting Service Department of the Philadelphia Electric Company presents no new radical or startling development in its central station practice, but has for its object a more thorough and systematic handling of the ever increasing details and importance of service.

The far reaching importance of the lighting phase of our work can best be described by quoting the opinion of Mr. Joseph B. McCall in his presidential address to the National Electric Light Association: "It is gratifying to find that increasingly greater attention is being given by all concerned in all parts of the world, and particularly in this country to the proper working out of our artificial illumination problems, particularly with relation to its effect upon the health and happiness of our citizens."

The lighting load of a central station is a very desirable one. The public is being educated on the subject of efficient lighting through the daily papers, magazines, advertising by the manufacturers of lighting units, central station engineers and the actual installations of improved lighting. Electric illumination is cheaper to-day than it was a few years ago, due primarily to the increased efficiency of lamps, and the prominence of illuminating engineering in central station practice.

The Philadelphia Electric Company has always been an exponent of the best and most efficient lamps procurable for its customers. Its knowledge of matters pertaining to the industry and of usefulness to its consumers has always been placed at their disposal. It early grasped the importance of illuminating engineering and educated its salesmen along these lines, realizing that a general knowledge of the subject by the selling force would be reflected by the installation. It organized an illuminating engineering department consisting of men well versed in the more

* An abstract of a paper presented at a meeting of the Philadelphia Section of the Illuminating Engineering Society, Philadelphia, Pa., January 21, 1916.

scientific applications of illumination, and able to cope with the new and varied conditions and placed this department at the services of its consumers without cost to them, through the agencies of newspaper, street-car and sign advertising, and general advertising matter and, also, the verbal offering of this service by the salesmen and other representatives.

An analysis of our records show many lamps other than high efficiency tungsten lamps connected to our lines. It is further evident that the commercial activity in lighting units and the many instances of utter disregard for efficiency in the matter of installations of lighting units, leaves much work to be done by the lighting specialists of our company.

The predominant factor of this work is, that this service seeks out the customer instead of waiting for him to take the initial step. Its fundamental principles are to co-operate wtih the sales force in laying out proposed lighting installations and compiling the necessary engineering and commercial data pertaining thereto, for the enlightenment of the proposed consumer. It co-operates with the district managers in holding the business connected to the lines, by pointing out to the consumer the faults of his installation and the necessary changes to make a well balanced and efficient installation.

The department consists at the presenı time of seven men with the necessary complement of clerks and stenographers. Its headquarters are at the main office where three of its men are located, the remaining four being assigned to other districts and making headquarters there. The district men report by 'phone to headquarters morning, noon and night, to keep in close touch and to follow cases needing immediate attention. All requests for information or complaints are called on within twenty-four hours and fully 75 per cent. within six hours.

On receipt of a request for information or a complaint from a consumer, either by personal call, telephone or letter, the person receiving such request, fills out a blank form known as "Office Notice to Service Department." This blank is in triplicate. The original is immediately forwarded to headquarters, the duplicate to the lighting service representative of the district and the triplicate retained for office files. If the case to be called on is in other than the district receiving the call, the information is given

over the 'phone to the proper districts and the blank forms follow in the company mail.

The same procedure is carried out by salesmen in requesting the aid of the department in preparing lighting plans for new or proposed installations or for changes in existing installations. Practically all cases of this character are handled by the lighting specialists stationed at headquarters, it being considered inexpedient to permit the district men to devote a considerable period of time—sometimes extending into several hours or even days on any one case, in which event they would often fail to give service to some consumer desiring immediate attention. They are, however, fully capable of handling the lighting problems coming before them, and care for all, except as stated, the large and extended ones.

The personnel of the department consists of men who have been connected with the company for extended periods and who have had technical training in the higher schools and colleges, or who have worked their way through the technical and engineering departments of the company. They must possess a thorough knowledge of the details of the company, and be well versed in the commercial phases. It is needless to say that men, assigned to this department, must possess a courteous and diplomatic personality.

There is no limitation placed upon the character of work. The consumer requesting an inspection of his house lighting for the purpose of seeing that his lamps are in good condition is accorded the same prompt and careful attention as the proposed lighting of a large factory, necessitating written specifications and plans.

Each district representative is in a measure held responsible for the lighting of the installations in his district, at least as far as his endeavoring to convert the consumer as to the errors of the installation. It is part of his duty to inspect, at night, the commercial lighting installations—at least one inspection per week must be made. These are reported to headquarters in a blank form in duplicate. The original is forwarded to the district office, who issues instructions on the triplicate form as previously explained, and the consumer is called upon.

These cases especially demand a diplomatic treatment, the manner of approach being an important factor in the results

obtained. Many of the consumers of the smaller business class look with suspicion on the first visit, and it can readily be seen that the salient point is to gain the consumer's confidence and assure him that the call is for his benefit. To immediately launch into the fact that a high efficiency lamp will cost him so much money, without first absolutely convincing him that it only consumes about half the current, would offset the results expected.

In all cases of lamp renewals where other than high efficiency lamps are placed, a pamphlet describing the efficiency of high efficiency lamps is mailed; these bring many requests for inspection and information. It is now contemplated to make a personal call on every such consumer for the purpose of explaining the advantages of this lamp.

THE DESIGN AND MANUFACTURE OF DIFFUSING GLASS SHADES.*

BY S. G. HIBBEN.

Synopsis: The direction and intensity of light from a given source is dependent to a large degree upon the contour of the shade or reflectors, upon the composition of these accessories and upon the extent to which the surfaces are cut or cast into prismatic forms or coated with reflecting substances. This paper deals with the laws which govern the manufacture and proper selection of *diffusing glass shades* as distinct from the prismatic or specularly reflecting shades. The *functions* of a lamp shade are given as: economical distribution, protection to the lamp, artistic design. Starting from these necessary characteristics the paper outlines the physical design, methods of manufacture, and details of shape affecting light distribution. A long series of tests were run on a representative group of sample shades of different shapes, color and material and theoretical and experimental curves are drawn for comparison. The paper closes with some tables of dimensional and photometrical characteristics for the intensive and extensive shades which were tested.

Among the various sources of artificial light that man has at his command, the metal filament electric lamp stands to-day as the most serviceable, economical and adaptable unit yet devised for general lighting service. Secondary in importance to the lamp, stands the shade or reflector, by means of which the light of the lamp is softened, controlled, and distributed in whatever manner is desirable or feasible.

The accessory, then, determines the results obtainable from the primary light source. Just as the shade (and the same may be said of the enclosing globe) is correctly or incorrectly designed and manufactured, so is the final utilization of light superior or inferior. By a correctly designed shade is meant one in which there are qualities of efficient reflection of light to useful areas and objects; efficient diffusion of light to avoid unevenness and harshness of illumination; efficient transmission of light under certain conditions of service; the satisfactory protection of the eye from direct vision of the lamp and satisfactory protection

* A paper presented before the Pittsburgh Section of the Illuminating Engineering Society, Pittsburgh, Pa., Dec. 17, 1916.

from resultant optical and physiological discomforts. The design of electric filament lamp shades is therefore a very important and necessarily complicated feature in the manufacture of lighting accessories.

This paper has for its purpose the presentation of the facts obtained from a study of the above mentioned factors of shade design. Its object is to consider the items necessarily involved in both theoretical and practical planning of the shapes and finishes of shades, noting meanwhile the limitations imposed upon the manufacturers in the present state of the glassmaker's art. It outlines the results of a preliminary study of the photometric actions of glass shades of various compositions, finishes and shapes, and describes the methods that have been devised and applied in the continued investigations of a particular type of shade of the "milk glass" or "light opal" composition, broadly known as a "diffusing type." Finally a presentation is made of the photometric actions of shades of this certain type, and a brief analysis is given of the methods to be followed in reflector design, based upon facts obtained from the results of a series of changes in the shapes of existing shades.

In order to understand the subject of design of shades, it is necessary to consider briefly the functions of a shade, and what may logically be expected of such an accessory operating under the best practical conditions.

Every incandescent filament lamp, giving off visible light by virtue of the heating action of an electric current, has a distinctive and peculiar character of light distribution. Each type of lamp, whether it be of carbon filament, oxide filament, or metal filament class, can usually be described in photometrical terms as having an "extensive distribution," or in brief, such lamps, placed with the axes vertical, will send the greatest portion of their light sidewise rather than downward. Even the few exceptions among lamps which have a downward or "intensive distribution," will fail to confine their light rays within economical angles, and even lamps which are inherently extensive in distribution will have a large portion of their rays inefficiently distributed in other directions. In general this inherent lack of economical distribution from the lamp itself, is the first reason for a reflector or shade.

The second function of a lamp shade is one of protection. Occasionally this takes the form of mechanical protection, or defense against exterior shocks, blows, or inflammable materials. More often, however, it is a question not of preserving the lamp or its surroundings but of protecting the eyes of the observers. Optical protection is highly important, and it is becoming more and more so as lamps become more and more intrinsically brilliant, and as more knowledge of optical hygiene is disseminated. The brilliancy of an exposed lamp filament is from one hundred to perhaps even one thousand times brighter than the eye can safely bear. A correctly designed shade must therefore soften this excessive brilliancy, either by enclosing the filament and so forming a secondary light source of very much larger radiating area, or by shielding the direct rays from the observer, or both.

The shade may add materially to the artistic qualities of the lighting unit, and this is the third reason for its use. It may be responsible for pleasing colors and pleasing shapes, and through its use the artificial illumination becomes a luxury in addition to a necessity.

Knowing then, that the shade is responsible for reflecting light and making it useful, for softening or shielding light and making it usable, and for decorating the light source and making it agreeable, it remains to be shown in this paper how such shade characteristics may be obtained. Particular attention will be given to the first or more scientific property of light reflection, control and distribution.

The range of investigation that is presented in this paper is confined to a study of the diffusely reflecting type of commercial shades, as distinguished from prismatic or specularly reflecting shades. The scientific design of this latter type of accessory has long been practiced, and has reached such a point of perfection that almost any desired redirection of rays can be secured. The only lack of absolutely definite control occurs when the light source is of large dimensions. The basis of this design is the law of specular reflection, where the angle between the incident light ray and the reflecting surface at the point of contact is always equal to the angle between the reflected ray and that surface. This law has been correctly applied to silvered glass reflectors, polished metal reflectors, prismatic shades and certain

glass shades with a very optically dense body and a high interior surface polish. Without modification it has been incorrectly applied to the design of shades that act by diffuse reflection, or diffusion. Fig. 8 presents a graphical conception of several dif-

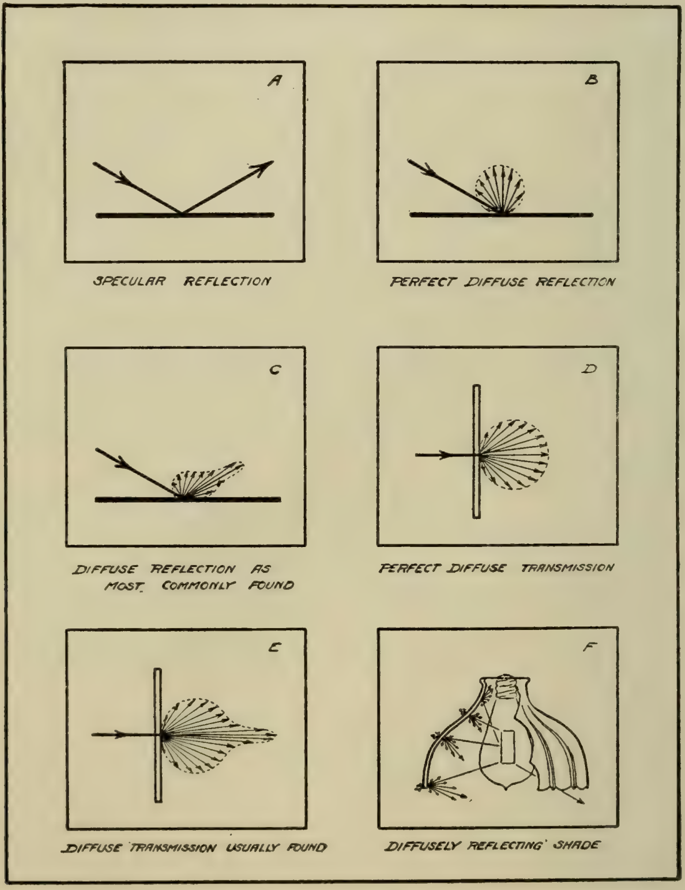

Fig. 1—Illustrating light control.

ferent characters of reflection, and illustrates the general action of a diffuse reflecting shade. It is at once conceivable where many previous designs of shades, based solely upon the law of specular reflection, have been in error, when such shades were composed of an inherently diffusing and diffuse reflecting medium.

Certain limitations are imposed upon the studies that this

paper presents. These limitations may be due to manufacturing and manipulating impracticabilities, or they may be due to placing necessary restrictions upon what otherwise becomes a vast subject.

It will help somewhat to first understand the general processes of manufacture of the white or "light opal" glassware herein discussed. This is what is commonly known as phosphate glass, representing the most universal type of diffusing glass, and possessing qualities of sufficient density in the shape of reflectors to allow a good reflection; and also qualities of good diffusion coupled with low light absorption to allow, in shape of enclosing globes, of efficient transmission. The "batch" or the unfused mixture of ingredients carefully proportioned by weight and in powdered form is shoveled into the open neck of a well dried and seasoned clay melting pot, and heated by natural gas flame to 1,000 deg. to 1,500 deg. C. Quite often there is added to the raw batch a quantity of scrap glass or cullet. The molten glass, after having been kept at a carefully adjusted temperature for a sufficient time to secure the right density and texture, is worked by dipping out the glass through the throat of the pot with blow-pipes, rods, or ladles. The glass, of a consistency about as very thick molasses, is gathered on the end of an iron rod, withdrawn from the pot and allowed to drip into the open mould. When sufficient glass has accumulated the operator cuts off the stream with a pair of shears, slides the mould beneath a plunger, and with a long lever presses the plunger down into the center of the mould, thus forcing the glass upward into the space between mould and plunger, the latter giving shape to the inner surface of the article. This is the "press-mould" process.

In the blown articles, the glass is dipped on a blow-pipe from the pot in a similar way, but the operator first by blowing, rolling, and swinging, secures a hollow sphere of glass on the end of his blow-pipe which he then inserts into a metal mould and blows up to final shape. If the article is vertically ribbed or elaborated, the operator may not twist his pipe when blowing the glass up in the mould, and such constitutes the "iron-mould" process. Otherwise the article is twisted as it is blown (to remove mould marks, etc.), and because of the graphitic material used to line such moulds, this is known as the "paste-mould" process.

Most of the reflectors herein investigated were made by the press-mould process, which does not allow of wide variation in shapes without excessive cost for new moulds, therefore the investigation of the photometric effects of different contours has made it necessary to change the shade curvatures by re-heating the shade after it has been removed from the mould and flaring it over temporary formers similar to inverted press-mould plungers. This treatment often determines the quality of glaze on the inner reflecting surface and care has to be taken to control or to allow for this effect.

Ordinarily the qualities of ornamentation are considered after those of scientific correctness, and in all of the investigations hereinafter outlined, the only attention given to the decorative feature was to originally select a design of shade that was pleasing in appearance, and to effect only those changes in contour which would leave a shape that seemed reasonable and graceful. Color, and purely ornamental elaboration cannot be further discussed within the limits of this paper.

The sizes of shades with which this study deals are confined in general to ones that are for use with 25-watt to 150-watt tungsten lamps, or five sizes in all. It is reasonable to assume that the performance of such sizes will be closely indicative of the performance of larger or smaller shades; furthermore these are the sizes that are in most common use. Two photometric types of shades were investigated, which will be referred to as the *extensive* or "Type E" and the *intensive* or "Type I" shades. Some few shades in common use are desired to be more focusing than type I, or more broadly extensive than type E, but such will be modifications of the above chosen types.

The detailed study of the light-reflecting and light-diffusing characteristics of the shades has been based upon tests made with a stationary photometer, and upon the results of such tests expressed graphically by vertical-plane distribution or polar distribution curves.

Such polar curves as plotted and as herein illustrated represent, therefore, the radiated intensities of light in the various directions from the units under investigation, and are indicative of the manner in which the shades are performing, since the polar distribution from the standard high efficiency lamps has a definite

known shape common to all wattages of lamps. The reader is presumed to be familiar with the interpretation of polar curves, hence further discription of the routine procedure in photometric testing is unnecessary. For the same reason the lengthy tabulation of original data is omitted.

THE PRELIMINARY STUDY OF INHERENT SHADE CHARACTERISTICS.

The Character of Transmission.

In addition to reflection, the redirection of light rays may be accomplished by passing them into or through refracting media, or by transmission through diffusing media. These methods are practiced chiefly in lense design, and in the design of enclosing globes, and do not deeply concern the present study. It may be said, however, that the peculiarities of diffuse transmission of the glass should be known before proceeding with the shade design. Tests were made upon transmission through flat glass plates of the same thickness as the walls of the shades, and from such tests it was found that a normally transmitted ray is diffused so that the emergent beam acts very much in accordance with the law of ideal diffusion, Fig. 1E, with the exception of having a higher value of transmitted light along the extended direction of the incident ray. The inherent property possessed by the glass (in pressed shades with walls 3/16 in. to 5/16 in. thick) of diffusing well whatever light is transmitted, make it unnecessary to further consider this feature, and it becomes only necessary to attempt to keep the total transmitted light to low values.[1]

In Fig. 2 one may note the difference between different glass densities, in two similar shades of identical size and contour. The denser glass transmits 13 per cent. less light to the upper zones, but reflects more light downward between the angles of 20 deg. to 90 deg. A slightly higher surface polish on the light-density shade has caused an increase of tip or downward candle-power; but being confined in a narrow cone, represents a very small lumen—or quantitative—increase in this direction.

Results similar to these have led to the adoption of a medium

[1] Transmission coefficients for tungsten lamp light will vary as follows:

Heavy weight (5/16 in. thick) pressed light density opal . . 60-50 per cent.
Medium weight blown heavy density opal . . . . 23-45 per cent.

density glass, and such a density was used in all of the diffusely reflecting shades with which this paper deals.

THE CHARACTER OF REFLECTION.

(*a*) *Specular Reflection.*—Reflection from the shades under examination has been found to be more or less diffuse in character, whatever may be the surface polish or finish. This does

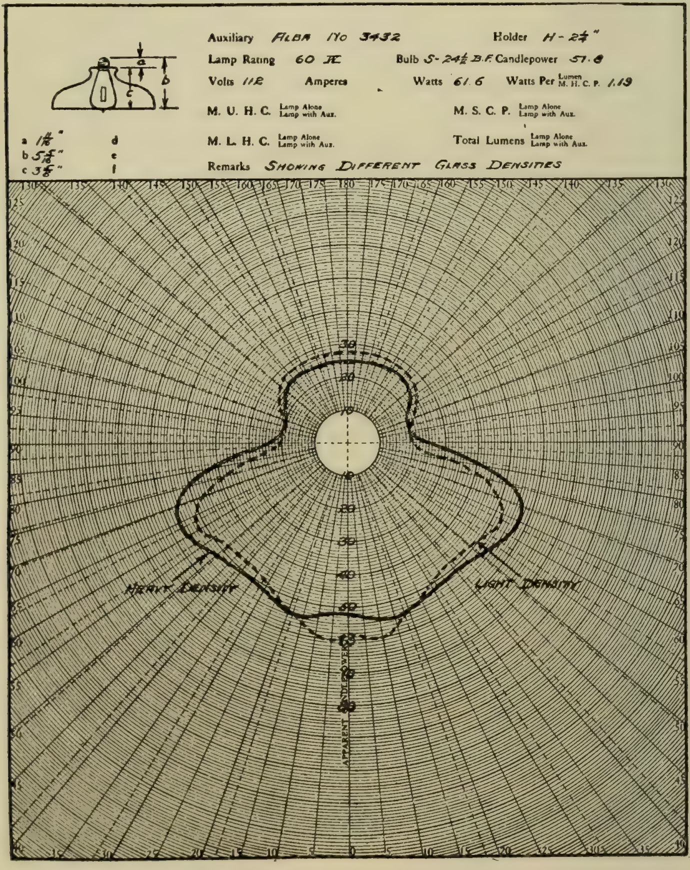

Fig. 2.—Different actions due solely to different glass densities.

not mean that the surface finish is not an important factor in the photometrical performance, but rather that in shades of this class, the body of the glass is also very largely responsible for the redirection of the rays. Note Fig. 3, showing the effect of sand-

roughing the interior surface of an alba glass shade. The transmission becomes less on account of the roughing, and the reflection also less in the zones where a large amount of modified specular reflection of light was occurring before. At the angles where no specular reflection of light was originally visible, the

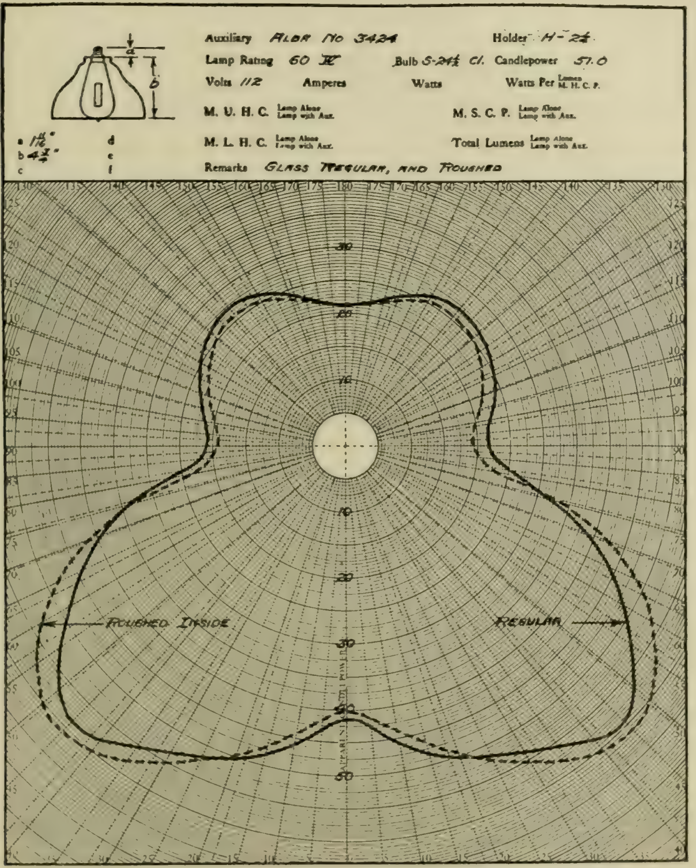

Fig 3.—Showing the effect of roughing the interior of the shade.

roughing caused a slight candlepower increase, due to a change from diffuse reflection to more nearly perfect diffusion. (See Fig. 1.)

It is reasonable to suppose that the minute suspended particles in the body of the glass act to reflect light (chiefly by specular

action) and that some slight reflection also takes place at the outer glass surface.

In designing prismatic or silvered glass reflectors one method is to use the law of specular reflection, first considering the light source as a point, and afterwards correcting for the barrel-shaped or comparatively large source that is formed by the filament of the tungsten lamps.

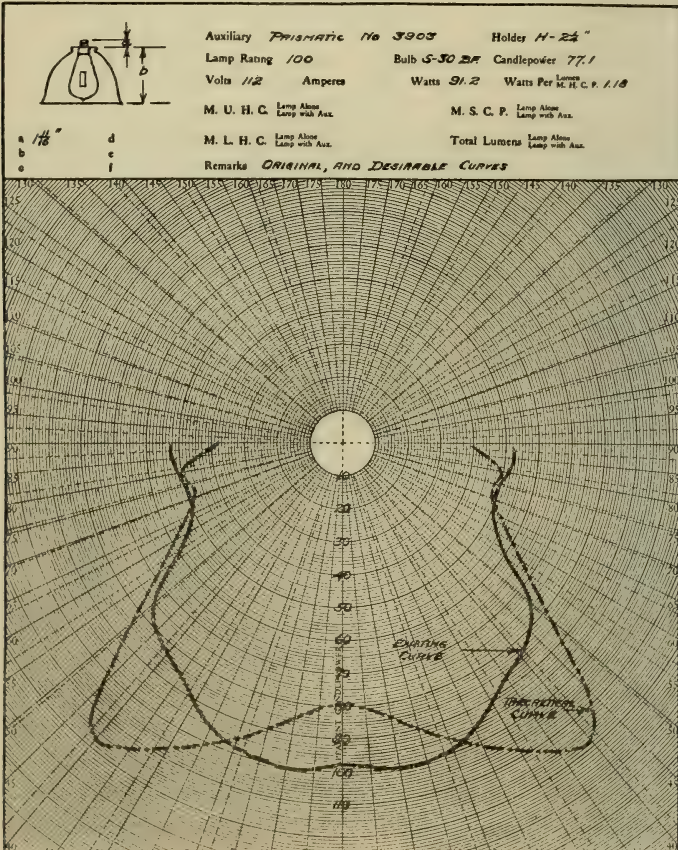

Fig. 4.—Original and desirable curves of a prismatic shade.

Ordinarily the various horizontal zones of prismatic (specular) reflectors, taken alone, will give sharp peaks on the polar curve, due to a minimum of diffusing action, and it is possible to change

the final curve of the unit by changing the inclination or slope of one or two comparatively narrow zones. In Fig. 4, the existing curve of distribution from a prismatic shade is represented in full-line and the desirable curve is broken-line. The several curves of Fig. 5 show the reflecting effects of four horizontal zones of

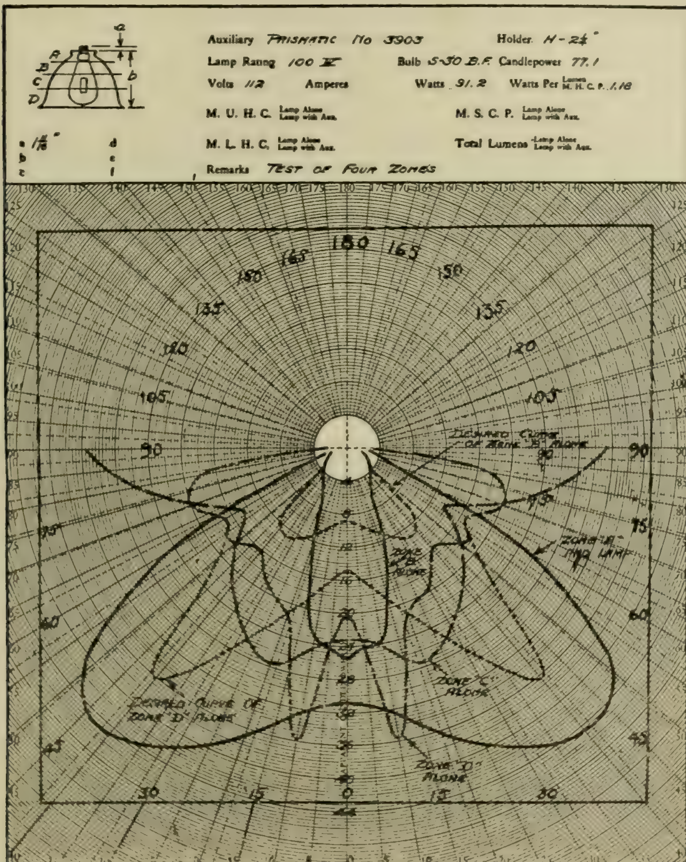

Fig. 5.—Tests of four zones of a prismatic reflector.

equal width. The outer curve represents the light from the lamp plus a slight downward-directed flux coming from the uppermost zone. The other curves are of the reflections from the respective zones alone, the direct light from the lamp having been subtracted.

Now in order to obtain the desirable curve of the unit of Fig. 4, zones "B" and "D" may be altered, to have their maximum reflection at the 40-deg. rather than at the 10-deg. angle. Such attempted changes in their curves are represented by the dotted lines of Fig. 5. For example the final intensity at the 40-deg. angle will be 116.5 candlepower, made up of

Zone B	13.0 candlepower
Zone C	22.0 candlepower
Zone D	36.5 candlepower
Zone A (and lamp)	45.0 candlepower
Desirable curve	116.5 candlepower

Zonular tests were made by covering all other than the active zone with a dead black light-absorbing paint (lamp-black, shellac and alcohol.) This example will suffice to show one of the means of studying the action of a specularly reflecting shade.

(*b*) *Diffusion.*—Just as the character of reflection in prismatic, silvered, or certain polished opaque shades is governed by a definite law, so does the "reflection" from the surface of a nearly perfect diffusing shade obey a primary law, although not quite so definitely. If the reflecting surface is a perfect diffuser, the incident beam will be broken up into a large number of non-parallel rays, having their maximum intensity along the normal to the surface. The intensities of the diffused rays may be represented as lying in the surface of a sphere, tangent to the diffusing surface at the point of incidence of the original beam. (See Fig. 1, B.) Changes in the direction of the incident beam will cause no change whatever in the direction of the diffused rays.

For this reason it becomes impossible to sharply change the distribution curves of shades made of nearly perfectly diffusing substances, and in fact very difficult without careful study to even moderately control their photometric action.

Consider Fig. 6, showing the bare lamp curve (dotted line); the ideal curve of diffusion (full black line); and the final composite curve (broken line). This would represent the action of a flat reflector of dense opal glass, heavily polished. In this example it is well to note that this shows (below the horizontal), a distribution that is characteristic of flat types of steel enameled shades. It may furthermore be said that in this and all other

cases of shade actions, there will always be downward intensities of light at least equal to those coming from the bare lamp, and lying in the unobstructed cone contained within the circle formed by the rim or lower edge of the shade.

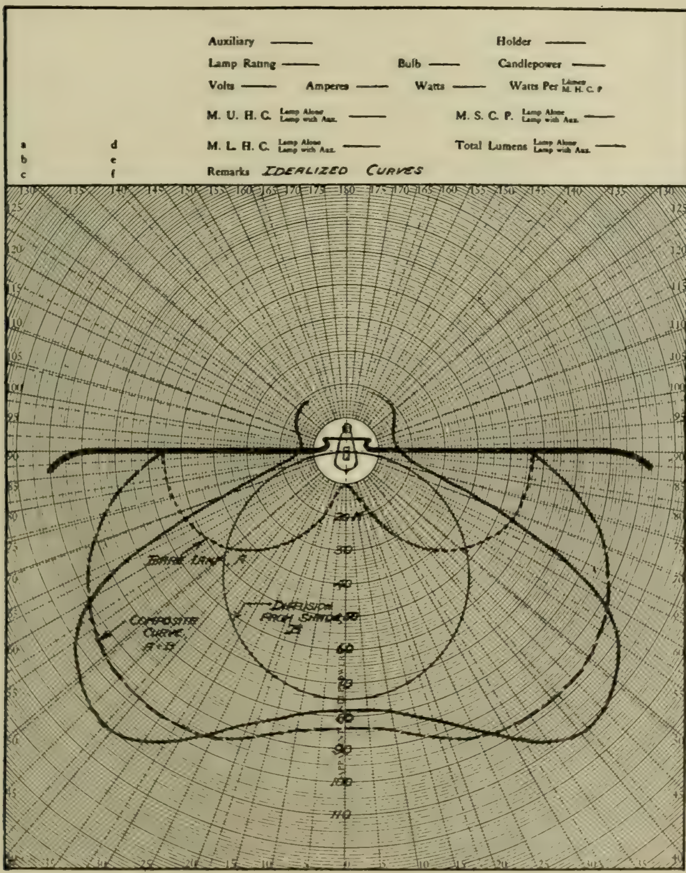

Fig. 6.—Idealized curves of a flat diffusing shade.

In Fig. 6, as the perfectly diffusing shade is made concave downward, with a narrowing mouth, the direct light from the lamp will be cut off more and more, while the intensities at angles just before eclipsing of the filament begins to occur will increase, and the general form of distribution becomes similar to this outer full-line curve of Fig. 6.

(*c*) *Diffuse or Spread Reflection.*—It is to be borne in mind that the diffusely reflecting glass shades under investigation are credited with possessing in part the properties of both types of shades previously discussed, *viz.*, they act by what is herein termed diffuse reflection, intermediate between pure specular reflection, and pure diffusion (Fig. 1, C). Some specular reflection occurs, for were this not true, it would be impossible to obtain such a type of distribution curve as is shown in Fig. 12 of a focusing character at the 0 deg. angle. Concentration of light within narrow angular limits is not possible with purely diffusing shades, and therefore such results as illustrated by Fig. 12, indicate that reflections from parti-specular opal glass shades is more controllable than reflection from shades of media similar to depolished porcelain enamel and roughed glass, etc. On the other hand, the moderately slight effect resulting from depolishing the inner surface of the shade of Fig. 3 leads to the assumption of its original action before parti-diffusing.

The problem of the design of light density opal glass shades, therefore, is not so easy as when dealing with a silvered glass type of shade, nor so closely limited as when dealing with solely diffusing media.

THE SELECTION OF GENERAL SHAPES OF SHADES.

Before proceeding with the investigation of diffusely reflecting extensive (Type E) and intensive (Type I) shades, it is necessary to eliminate those classes of shades which by virtue of their original shapes would be classed as optically or photometrically unworthy of study.

Flat types of shades, as illustrated in Fig. 7, and giving the characteristic distribution of Fig. 8, are prohibited since they offer no protection to the observer's eye. They intercept only a small portion of the light rays, not much over one half, and cannot give an efficient focusing distribution. They may increase slightly the light at a wide angle (just before the skirt of the shade cuts off direct rays) due to reflection from the lower rim; and they usually cause a slight peak in the curve of the 0 deg. zone due to reflection from the neck and from a narrow band just above the lower rim.

The deep-bowl and straight-sided shades, shown in Fig. 9, have

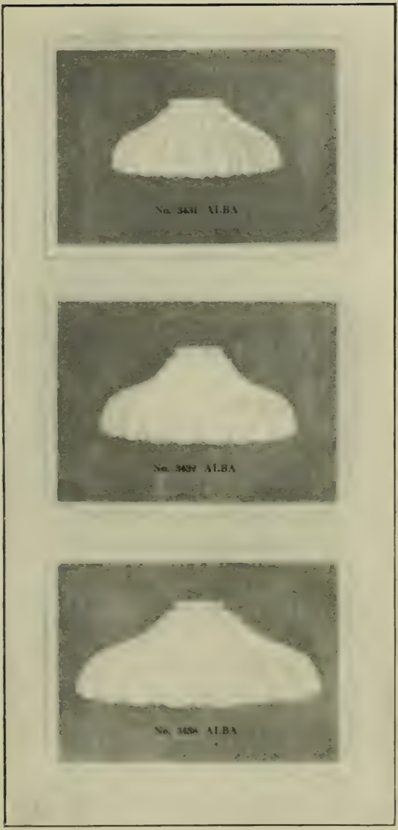

Fig. 7.—Shades too shallow for optical projection.

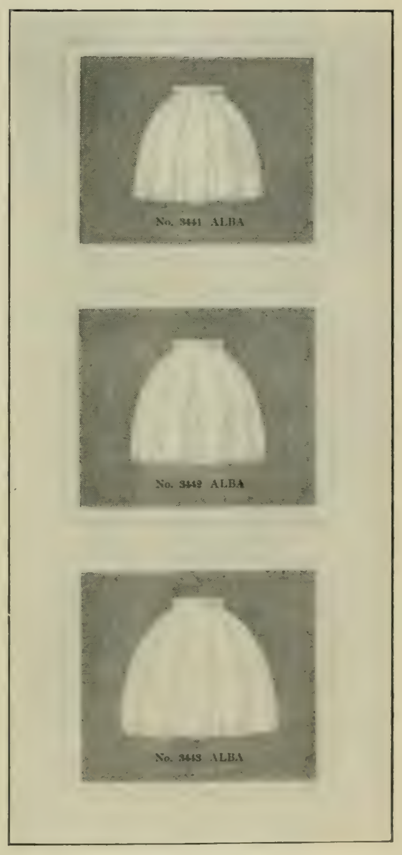

Fig. 9.—Shades too narrow for efficient reflection.

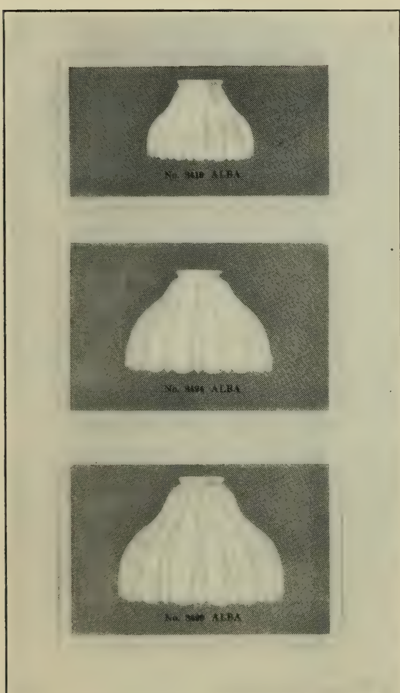

Fig. 11.—Shades of intensive type.

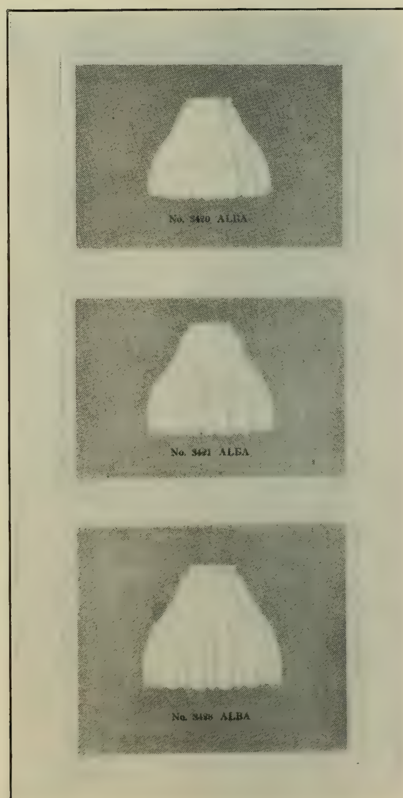

Fig. 13.—Shades of extensive type.

many multiple interior reflections and radiate the light sidewise, principally by transmission. Their characteristics are typified by Fig. 10. The slope of their walls is too nearly vertical for a focusing action, and only the neck specularly reflects the light downward. Excellent for bracket lighting and similar service, they nevertheless fail to qualify among the strictly E and I types.

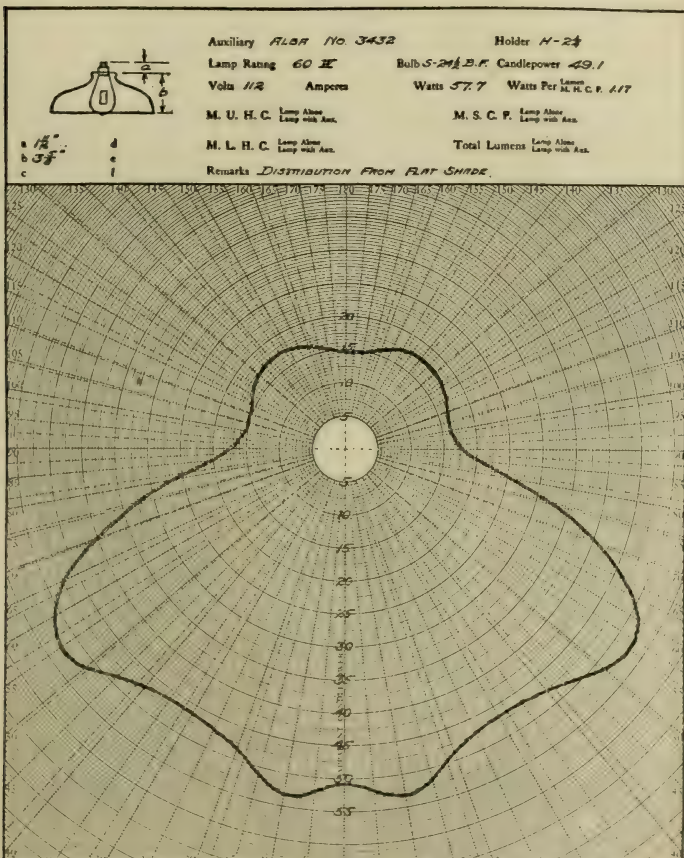

Fig. 8.—Characteristic distributions from flat shade.

Fig. 11, and the curve of Fig. 12, show a type of shade that may be intensive in distribution and on account of the depth and graceful contour, was chosen as one of the classes to be further investigated. A second chosen shape is illustrated by Fig. 13,

this also having pleasing proportions and affording optical protection. Its characteristic distribution is extensive when the light source is correctly placed in it, as shown by the full-line curve of Fig. 14.

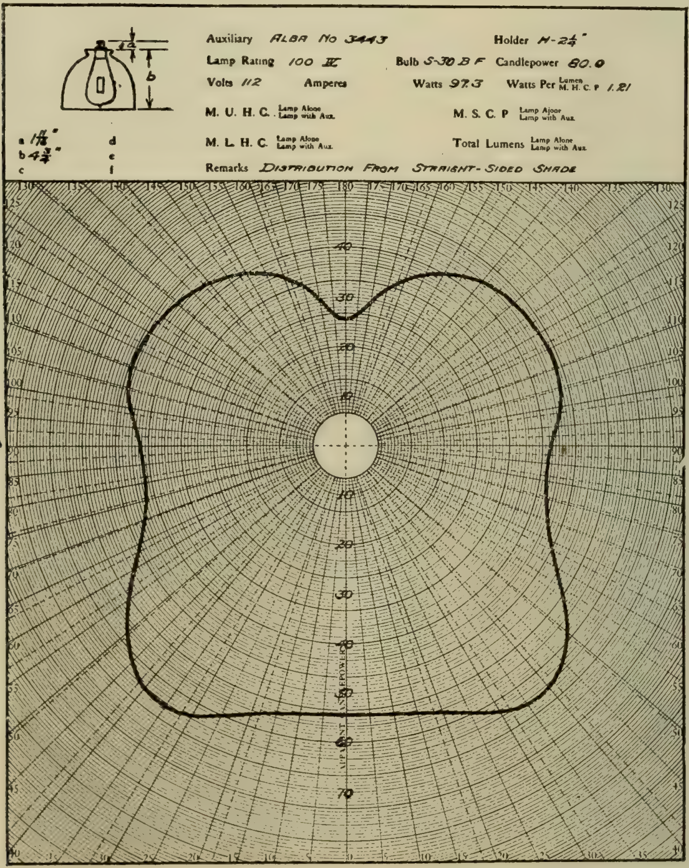

Fig. 10.—Characteristic distribution from narrow shades.

These two latter classes were therefore chosen as the most acceptable ones, and a further study of their reflecting actions is hereinafter given.

The Mechanical Testing Apparatus, and Shade Manipulation.

(*a*) *The Contour Drawing Apparatus.*—In the study of effects

of changes of contour, it is necessary to know the curvature of the inside surface of various shades. As these shades are perhaps warped or changed slightly in cooling, no exact dependence may be placed upon the original design-drawing as representing

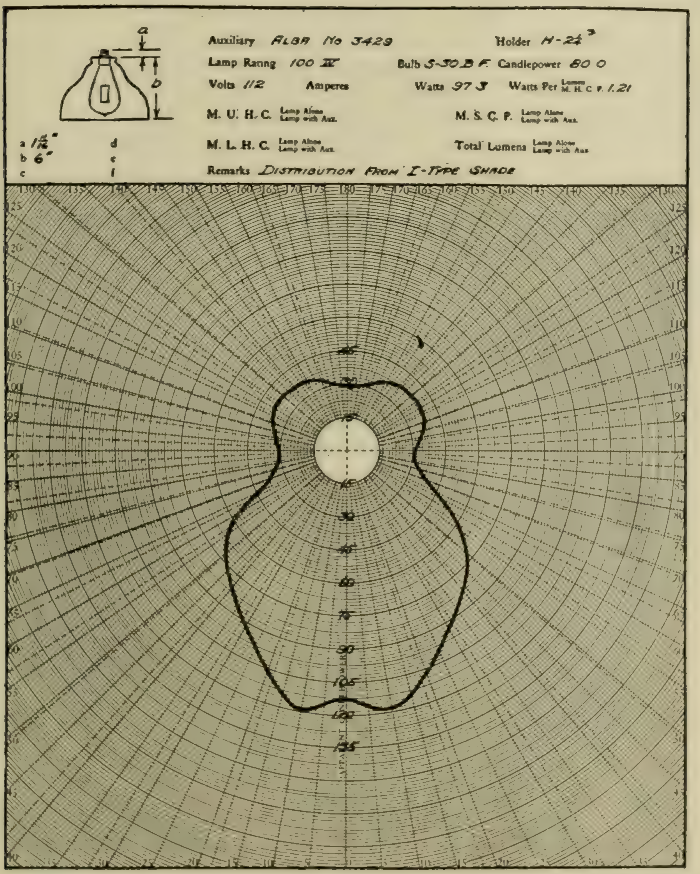

Fig. 12.—Characteristic distribution from I-type shade.

the finished article, at least so far as concerns these shades that are manufactured for special testing purpose. Furthermore the shades may have been put through a series of changes during their investigation, and at each change the contour must be known.

During the most of the tests that are presented in this paper,

the interior curvatures were obtained in each case by making a plaster-of-paris model about 1 in. in thickness, and across the maximum diameter of the shade. This model after removal was cut into two sheets on a saw, and the curvature at the cutting line would then be the shape of the interior surface.

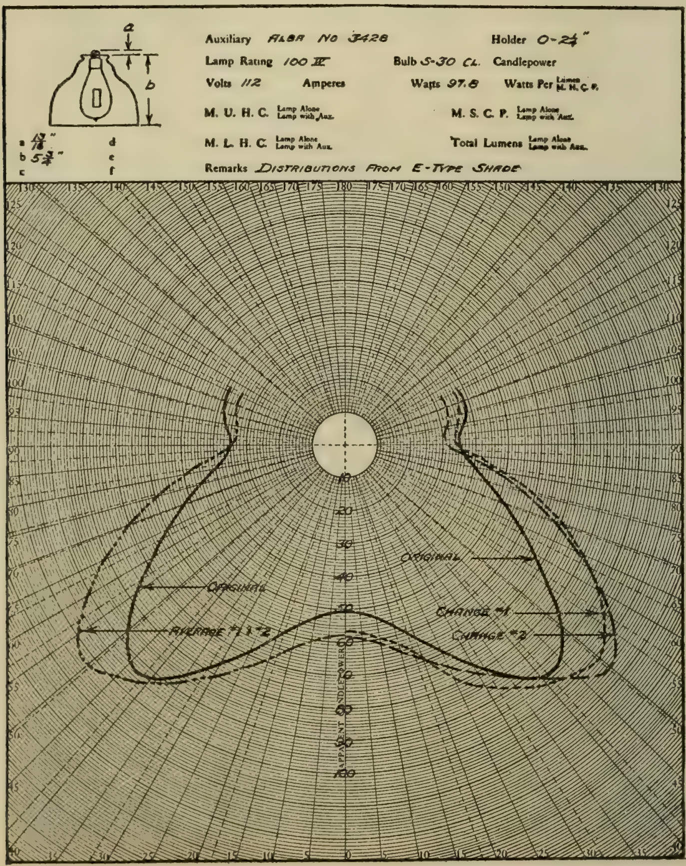

Fig. 14.—Characteristic distribution from E-type shade.

This method was exact but tedious. During these investigations a device was invented by the author to accomplish the same thing with much less labor, consisting of a drawing machine as shown in plan by Fig. 17. This consists of the board, having two clamping devices (C-C′) at its upper end to hold the com-

plete shade, and bearing a sheet of paper attached to its face with thumb tacks. A geared pinion adjustable in a slot, engages two racks, and the action is such that as the tracing pointer (A) follows the interior surface of the shade, the tracing pencil will exactly reproduce the curvature.

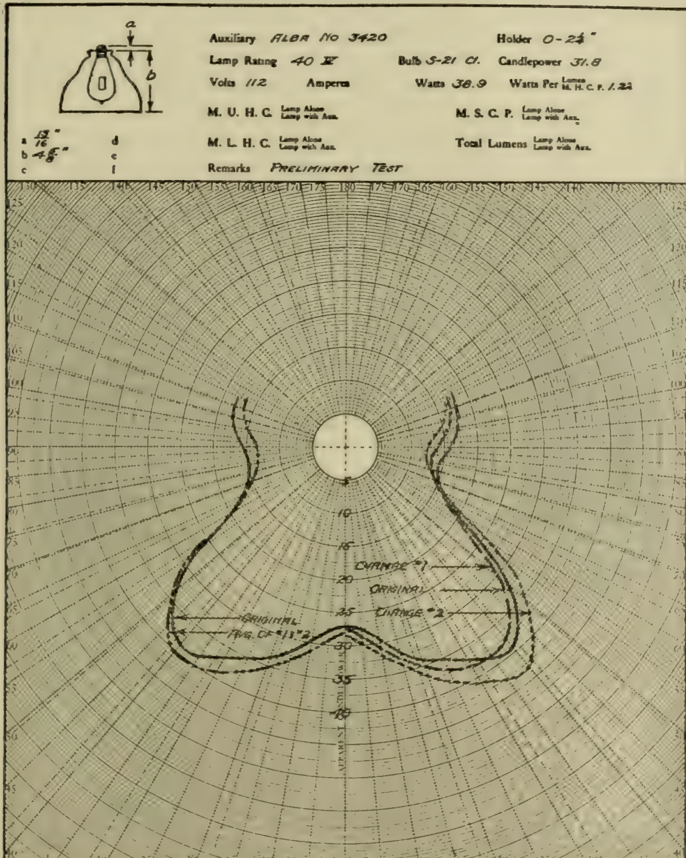

Fig. 15.—Showing effects of preliminary changes.

(*b*) *The Shade Manipulation.*—The process of changing the contour of existing shades was as follows: Having determined by calculation and observation the approximate shape desired, this shape (from a drawing) was reproduced in graphite coated wood or metal, similar to the plunger of a press, and the shade,

still hot from the press, was inverted and forced down over this former. Occasionally the flaring could be done off-hand when this flare was only at the lower edge of the skirt of the shade.

The photographs of Fig. 18 depicts three stages in the flare of a shade. These shapes illustrate changes in the skirt only,

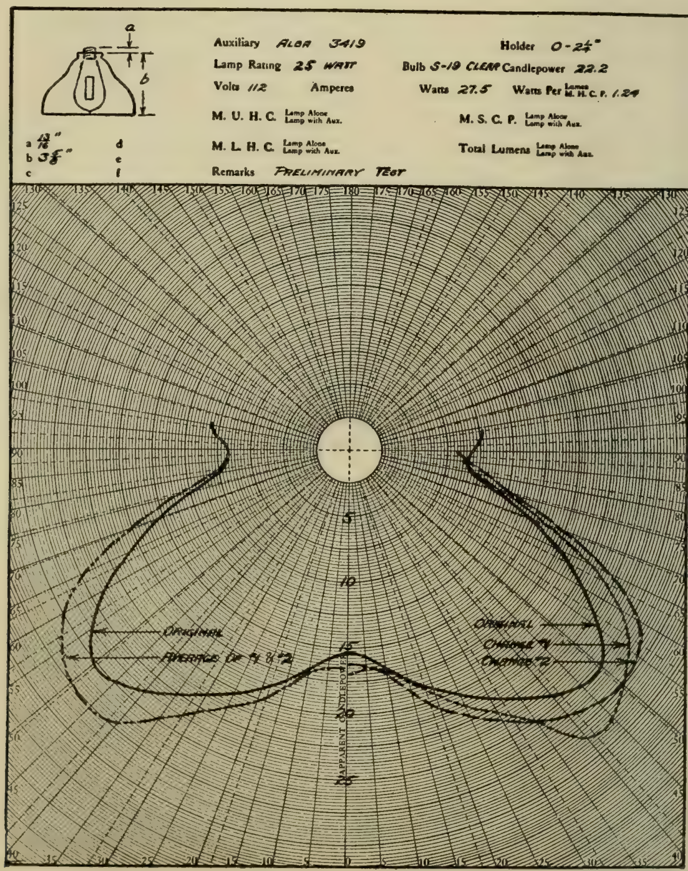

Fig. 16.—Showing effects of preliminary changes.

since the upper quarter of this shade remains practically the same. Note that the shade is lowered by each change in the diameter, so that the angle of cut-off of the direct light is increased by flaring. It follows that as a shade is flared in the process of making it focusing, there is a counteracting tendency

of its rather becoming extensive in distribution due to this direct light from the filament, which effect must be guarded against by careful design.

The Preliminary Study of Changes in Contour.

Having selected the general types of diffusely reflecting shades for a study of their characteristics of extensive and intensive distribution, it was thought advisable to briefly investigate the probable effect of the changes in contour that might be accomplished.

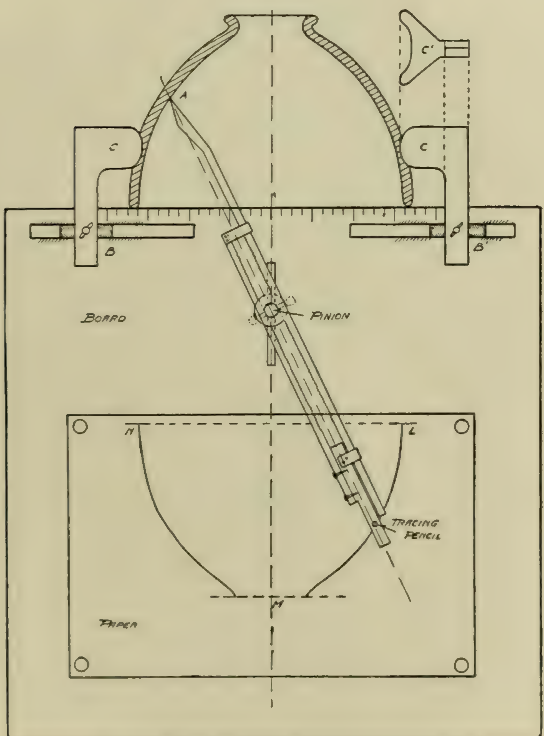

Fig. 17.—Shade contour drawing apparatus.

As previously stated, such changes in the pressed shades must be made after the moulding. These changes are made by reheating the skirt of the shade in a special furnace, and reshaping over a temporary former. Many difficulties are experienced in this work such as color changing, warping, etc.

Three shapes of shades were first taken, whose original contours are as shown by Fig. 11, number 3419; and Fig. 13, numbers 3420 and 3428. Their original distribution curves are given by the full-line plots of Figs. 14, 15 and 16.

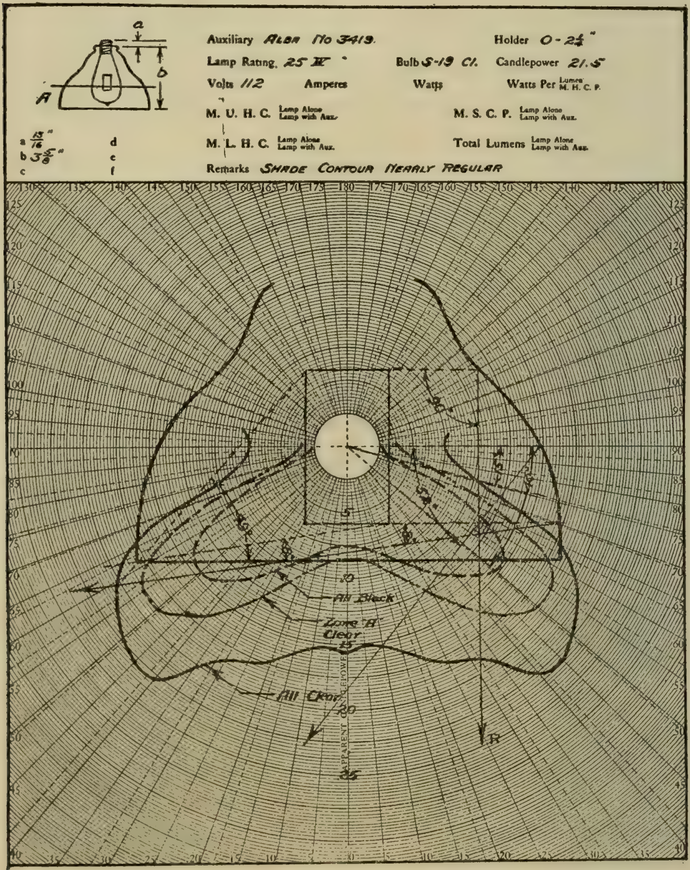

Fig. 19.—E-type characteristics.

Shade number 3428 of Fig. 14 was desired to be more extensive, or to have the maximum intensity of its photometric curve changed from 40 deg. to 45 deg.-50 deg. The long-dotted and the short-dotted lines show results of slight preliminary changes, and the broken curve of the left side of this figure rep-

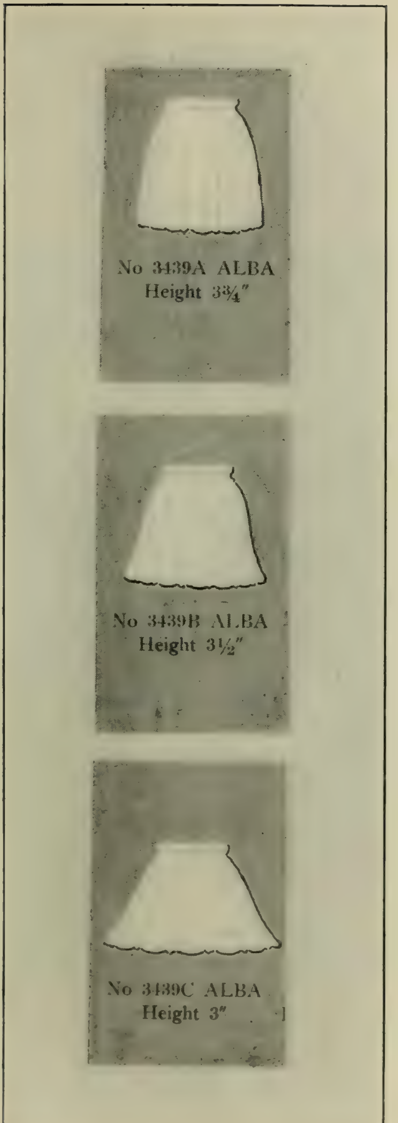

Fig. 18.—Illustrating steps in the process of flaring.

Fig. 33.—Changes in reflecting action caused by contour change.

resents the average change. This indicates a large possible improvement.

Similarly, shade No. 3420 of Fig. 15 was shown to be improved in the downward intensities and the shade No. 3419 of Fig. 16 was improved quite considerably in the zone between 10 deg. and 70 deg.

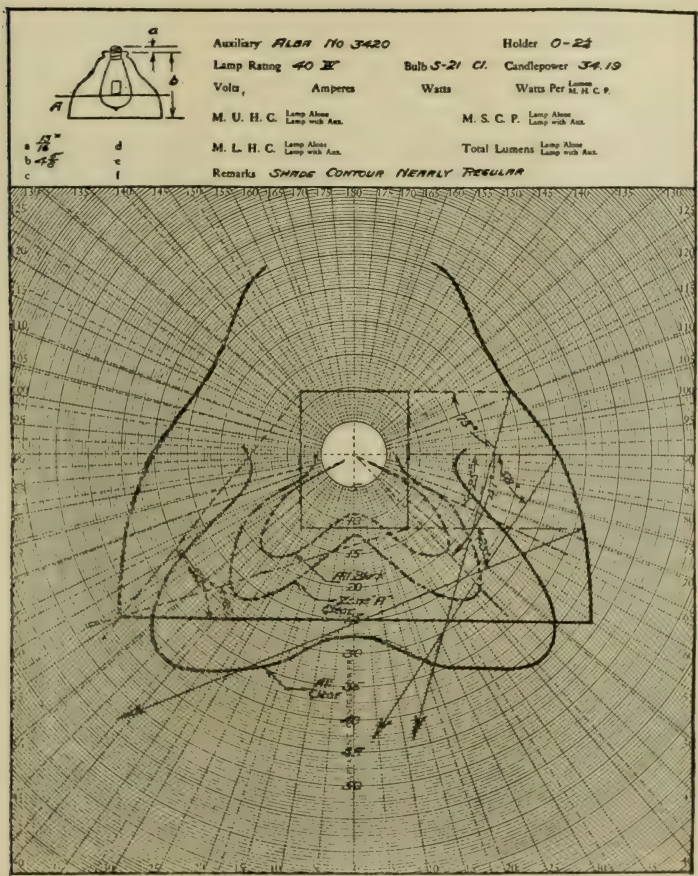

Fig. 20.—E-type characteristics.

These results were sufficient to encourage further changes, and indicate the possibility and in fact the desirability of very important improvements.

Changes in Type E Shades, and Results.

It has been advisable to supplement the theoretical considerations of the photometrical action of various shades by practical tests of their performance, and these following paragraphs deal with the study of the effects of changes of contour, and effects of lamp-filament positions.

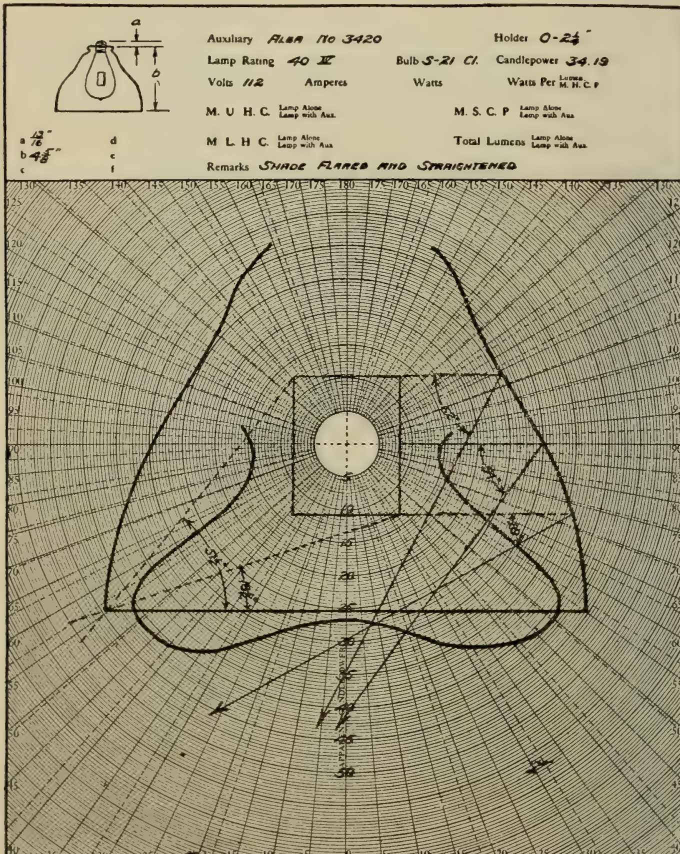

Fig. 21.—E-type characteristics.

All shades tested in this and the following cases, were standard types and were used with regular tungsten lamps. The filament position was fixed by the use of standard shade holders, so that all conditions would be as is found in common practice. Results are shown graphically in the Figs. 19, 20, 21, 22, 23, and 24.

In several cases, zonular tests were made to gain a further insight into shade action. Curves showing the result of such tests are recorded by the broken line plats. The beginning and the end of the cut-off of direct light is shown, measuring angles from the horizontal, which would be the same as the angle of tilt of the

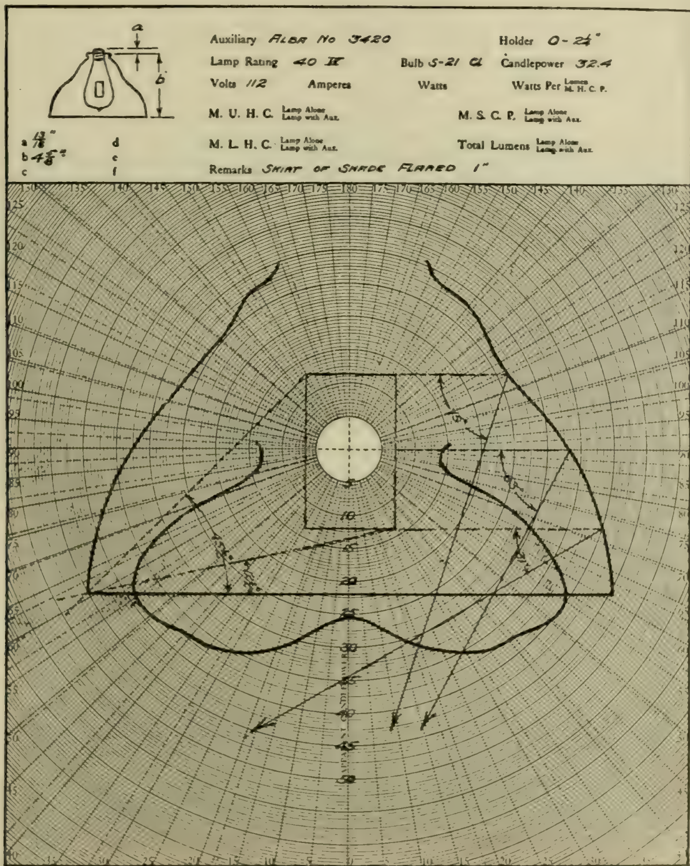

Fig. 22.—E-type characteristics.

axis of the shade from the vertical when considering exposure to commence at the smaller angle, as the mouth of the shade is gradually pointed towards the observer. The angles of specularly reflected rays that go out horizontally from the top, middle, and bottom parts of the filament are shown by the lines with

arrow heads. The direction of maximum intensity in pure diffusion would, as previously explained, lie on the bisectors of the angles between the incident and the reflected ray.

It was necessary to observe certain requirements as a basis for

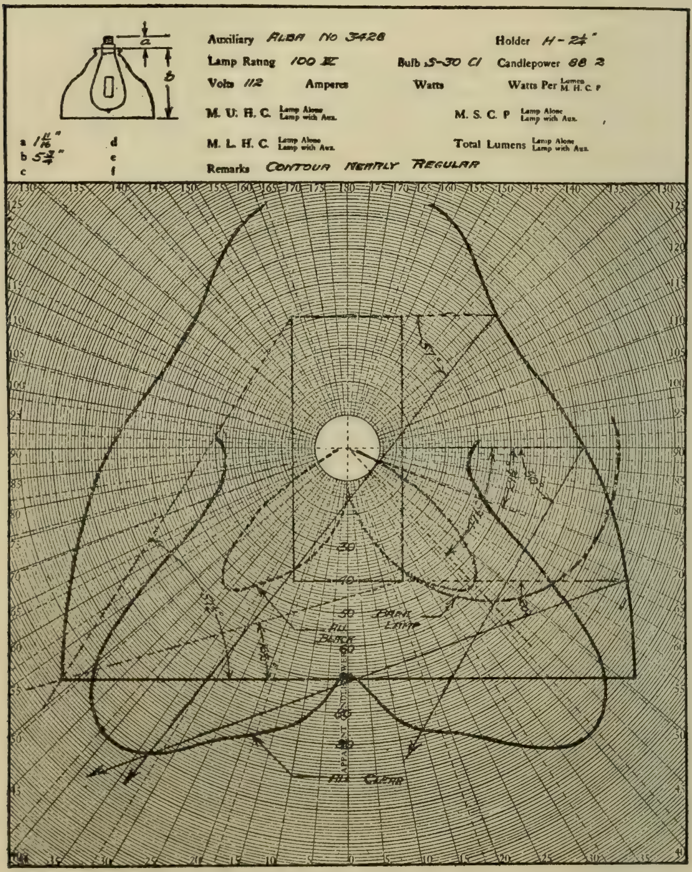

Fig. 23.—E-type characteristics.

these investigations, which requirements were determined from previous knowledge, and which are given in the following table. The shade dimensions are determined (1) by a height sufficient to shield the lamp filament, and (2) by a diameter in proportion to the height, that allows grace of outline and correct average slope of the shade walls. The absorption values are kept as low

as possible in all designs. Quite a range is offered for the photometrical determinants of E and I types, and it is sufficient in general to attempt concentration to the 45 deg. and 0 deg. angles respectively, in the preliminary designing of these types.

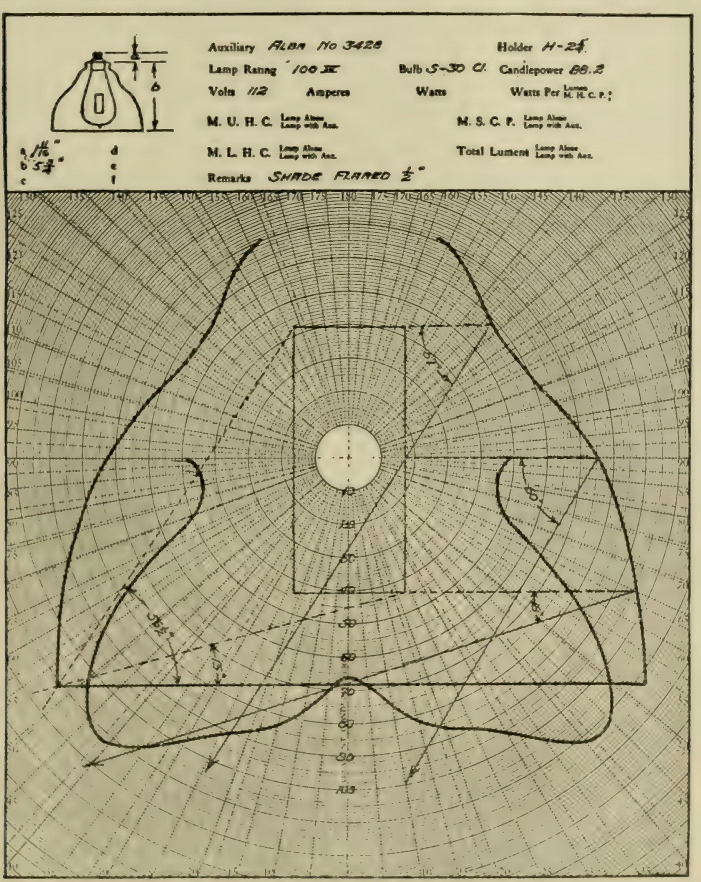

Fig. 24.—E-type characteristics.

Fig. 19 shows a shade that is extensive in distribution chiefly by virtue of the low position of the filament, or the resultant small angle of concealment. The test of this shade's lower zone or skirt—all but zone *A* being blackened—shows that this is a region of the shade which tends towards very extensive distribution. It is interesting to note the curve of direct light only, obtained with the shade entirely blackened.

TABLE I.—REQUIREMENTS.

Preliminary Standards Chosen as a Basis of Shade Design. Electric Shades to Give Extensive Distribution, Designated as Type E.

Tungsten lamp	Type holder	Height (inches)	Diameter (inches)
25-watt clear	O	4 –4½	4¾– 6
40-watt clear	O	4 –4¾	5¼– 6¼
60-watt bowl frost	O or H	5 –5½	5½– 6¾
100-watt bowl frost	H	5 –6	6½– 8½
150-watt bowl frost	A	5¾–6¾	9½–10¾
250-watt bowl frost	A	6 –7½	10½–12½

REMARKS.

All the shades of this type to be of a glass that is inherently diffusing in character, and to have the power of reflecting light from their interior surface and from the body of the glass only, and not from exterior prisms or superficial coatings.

All shades to be of an approximate deep bowl or bell shape.

All shades to cause a reduction of the mean spherical candlepower of the bare lamp by an amount not exceeding 15 per cent.

All shades to give a candlepower value at 45 deg. from the nadir of from 10 to 60 per cent. greater than at the nadir, or 0 deg. angle.

This curve represents the lower portion of the curve as it would be for the exposed bare lamp, with the reduction of intensity beginning at the 50 deg. angle, due to interception of direct rays by the shade rim. Some very slight unpreventable diffusion from the blackened surface of the shade causes a slight increase in candlepower at the zero angle over that which would occur from the lamp when used alone. Zone *A* though nearly vertical, yet increases (by diffusion) the directly downward light by an amount shown by the difference near the 0 deg. angle between the two broken-line curves. The zone having the most nearly 45 deg. angle slope, or just below the neck, acts to increase the downward light as the ray *R* of Fig. 19 would indicate, and diffused light coming from above zone *A* increases the candlepowers throughout the whole cone between the 60 deg. angles or elements.

Fig. 20 may be discussed in much the same way, noting that a higher relative lamp position causes zone *A* to reflect at less wide angles, and causes the interception of direct rays to commence at 37½ deg. (90 to 52½ deg.). The average slope of the upper middle portion of the shade being nearly vertical, causes the specularly reflected rays to lie chiefly between 20 and 45 deg.

By comparing this Fig. 20 with Fig. 21, one may note the effect

of straightening the shade walls. The action of diffuse reflection plus the specular reflections causes the angle of maximum intensity to increase from 45 to 47 deg.

Fig. 22 shows the focusing tendency of the same shade when flared 1 in. at the skirt. The effect is felt mostly by the rays sent out broad-side from the filament and which build up the final curve at about 25 deg., to 35 deg. angles. Eclipsing of direct light does not occur so soon, consequently the maximum intensity is at a higher angle than in the previous example.

The next two cases, Figs. 23 and 24, are not radically different in their presentation of the effects from flaring. Compare in Fig. 23, the curve of the bare lamp with the curve of the blackened shade, and note that although the eclipsing of the filament begins at 32 deg., yet the building-up action of the increasing broadside area of filament more than balances the decreasing effect of screening, up to about 10 deg. further.

The tabulated values of the following table give the characteristics of the above mentioned cases. These tables and the curves of these various cases are worthy of considerable study. They contain more information than may be mentioned here in detail, and their comparison and analysis will reward the scientist with quite some insight into diffusely reflecting shade action.

TABLE II.—TYPE E SHADES.

Dimensional Characteristics.

Figure	Shade	Lamp	Diam. mouth	Exposure* begins, degrees	Exposure* complete, degrees
19	3419	25-w.	4.75	8.5	49.0
20	3420	40-w.	5.25	18.0	52.5
21	3420	40-w.	4.41	18.5	51.5
22	3420	40-w.	5.88	12.5	45.5
23	3428	100-w.	6.53	16.5	51.5
24	3428	100-w.	6.63	15.0	56.5

Photometrical Characteristics.

Figure	Shade	Angle of max. I, degrees	Upper ray angle, degrees	Middle ray angle, degrees	Lower ray angle, degrees
19	3419	42	90	52	8
20	3420	43	75	75	23
21	3420	47	62	54	29
22	3420	53	73	63	31
23	3428	40	57	60	20
24	3428	42	57	60	18

* These angles represent the angular tilt of the vertical axis or the angles of depression of the observer's eye below the horizontal axis. Complimentary angles must be taken when reading these angles direct on the polar curve charts.

CHANGES IN TYPE I SHADES AND RESULTS.

Just as, in the previous section, there were presented several figures and a discussion of extensive distributing shades, so in this division Figs. 25 to 32 inclusive show steps in the changes made in the study of intensive types of shades.

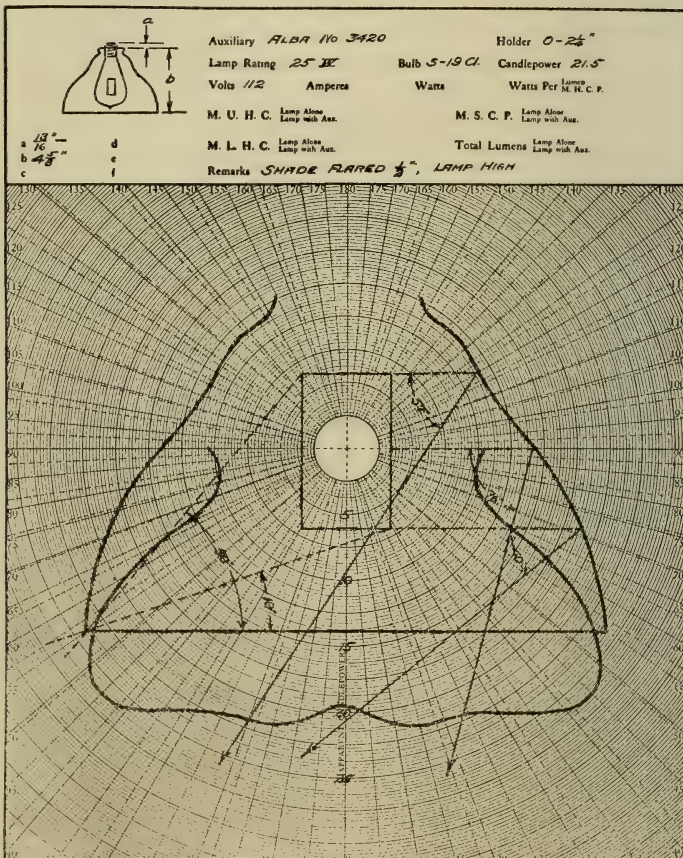

Fig. 25.—I-type characteristics.

Figs. 25 and 26 illustrate the effect produced by a change in lamp filament position, the shape of the shade being the same in the two cases. The horizontally projected light from the upper region of the filament is directed downward at about the 20 deg. angle, so the second curve is practically the first one plus an

increase at this point. It seems that this shade, when used as in Fig. 26, could be made intensive by additional broadening just above the lower rim.

The shade of Fig. 27 obviously is incorrect in the skirt for a true focusing action and has too large an exposure of bare fila-

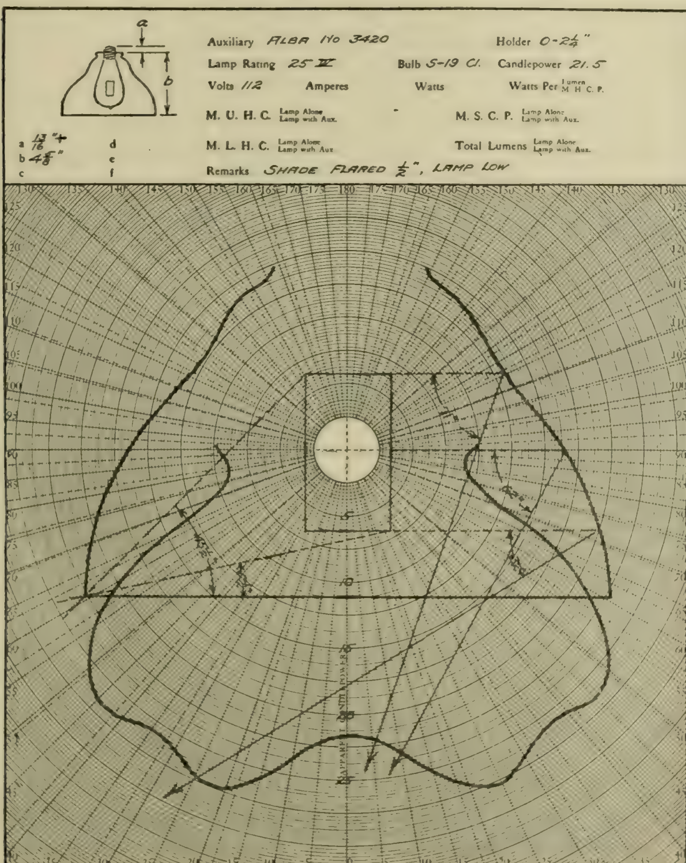

Fig. 26.—I-type characteristics.

ment. A better lamp and shade combination is shown in Fig. 28. Were the neck slightly more contracted, thus to give greater slope to the extreme uppper shade walls, and were the concave portion less deep, so that light from the upper filament would be directed downward, this shade would be very excellent.

Figs. 29, 30 and 31 show stages in the process of making a 60-watt intensive shade. Zone *A* of Fig. 29 which ordinarily would be the region giving the most extensive distribution is specularly active at about a 70 deg. angle, as ray *S* would indicate, but the cut-off is so early (as the dotted line curve shows)

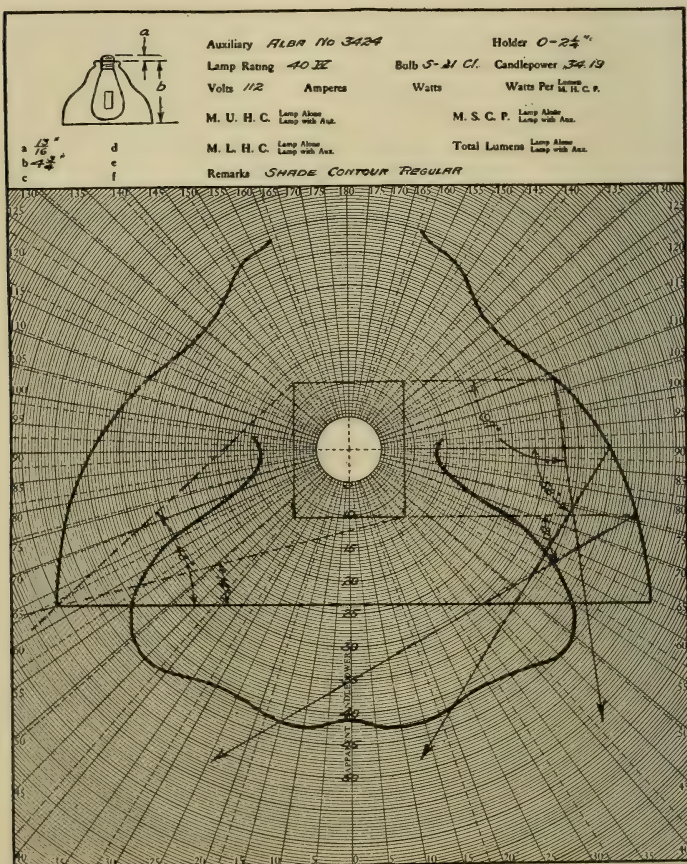

Fig. 27.—I-type characteristics.

that there is small resultant spread of light. The shape of shade No. 3421 is approaching the desirable curvature, and appears to need correction only in the neck, plus a very slight bottom flare.

The 150-watt shade and its curve of Fig. 32 illustrate an intensive type whose photometric action would be almost purely

intensive if the skirt of the shade could be sloped to have a downward specular reflection, and a diffuse or spread reflection at very nearly the same angle. Maximum diffusion would then occur at perhaps the 45-deg. angle.

It is interesting to note that the peaks on the curves, occurring

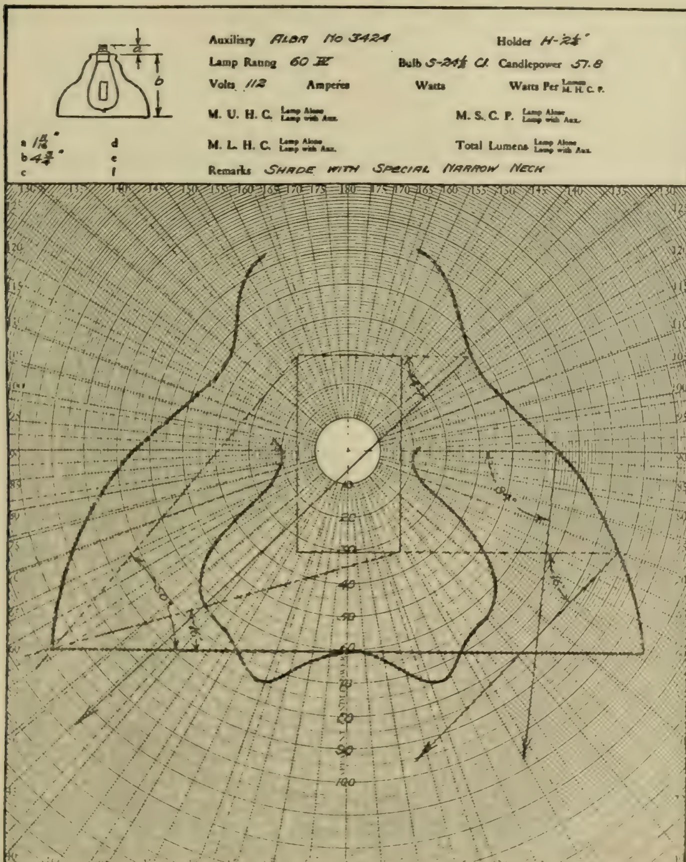

Fig. 28.—I-type characteristics.

at about the 10 deg. to the 15 deg. angles are due almost solely to specularly reflected light. It is generally characteristic of this class of shades that the lower hemispherical curve is in part similar to the composite curve of Fig. 6, with these peaks or humps superimposed thereon.

The preliminary requirements of Type I shades, and the tabulated characteristics of the shades discussed, are given in the following tables.

TABLE III.—REQUIREMENTS.

Preliminary Standards Chosen as a Basis of Shade Design. Electric Shades to Give Intensive Distribution, Designated as Type I.

Tungsten lamp	Type holder	Height, inches	Diameter, inches
25-watt clear	O	4 –4½	5 – 6¼
40-watt clear	O	4 –4¾	5¼– 6½
60-watt bowl frost	O or H	5 –5½	5½– 7
100-watt bowl frost	H	5 –6	7¼– 9
150-watt bowl frost	A	5¾–6¾	9½–11
250-watt bowl frost	A	6 –7½	11 –12¾

REMARKS.

All the shades of this type to be of a glass that is inherently diffusing in character, and to have the power of reflecting light from their interior surface and from the body of the glass, and not from exterior prisms or superficial coatings.

All shades to cause a reduction of the mean spherical candlepower of the bare lamp by an amount not exceeding 16 per cent.*

All shades to give a candlepower value at 45 deg. from the nadir of from 10 to 40 per cent. less than at the nadir, or 0 deg. angle.

* It is usually found that intensive or focussing shades have a lower absolute efficiency than extensive shades.

TABLE IV.—TYPE I SHADES.

Dimensional Characteristics.

Figure	Shade	Lamp	Diam. mouth	Exposure begins,* degrees	Exposure complete,* degrees
25	3420	25-w.	5.88	19.0	50.0
26	3420	25-w.	5.90	12.5	45.5
27	3424	40-w.	6.78	14.0	43.0
28	3424	60-w.	6.70	16.0	50.0
29	3421	60-w.	5.80	20.0	56.5
30	3421	60-w.	6.27	16.5	53.0
31	3421	60-w.	6.56	15.5	51.5
32	3446	150-w.	6.70	7.5	47.5

Photometrical Characteristics.

Figure	Shade	Angle max. I, degrees	Upper ray angle, degrees	Middle ray angle, degrees	Lower ray angle, degrees
25	3420	45	57	76	40
26	3420	23	71	62	32
27	3424	45 (?)	97	58	30
28	3424	21	44	84	46
29	3421	11 (?)	43	75	24
30	3421	38 (?)	54	76	24
31	3421	10 (?)	47	78	35
32	3446	7	88	57	10

* These angles represent the angular tilt of the vertical axis or the angles of depression of the observer's eye below the horizontal axis. Complimentary angles must be taken when reading these angles direct on the polar curve charts.

SUMMARY AND CONCLUSIONS.

It has been outlined what were the functions of a shade, and how highly important, if correctly designed, this accessory becomes in the best utilization of light.

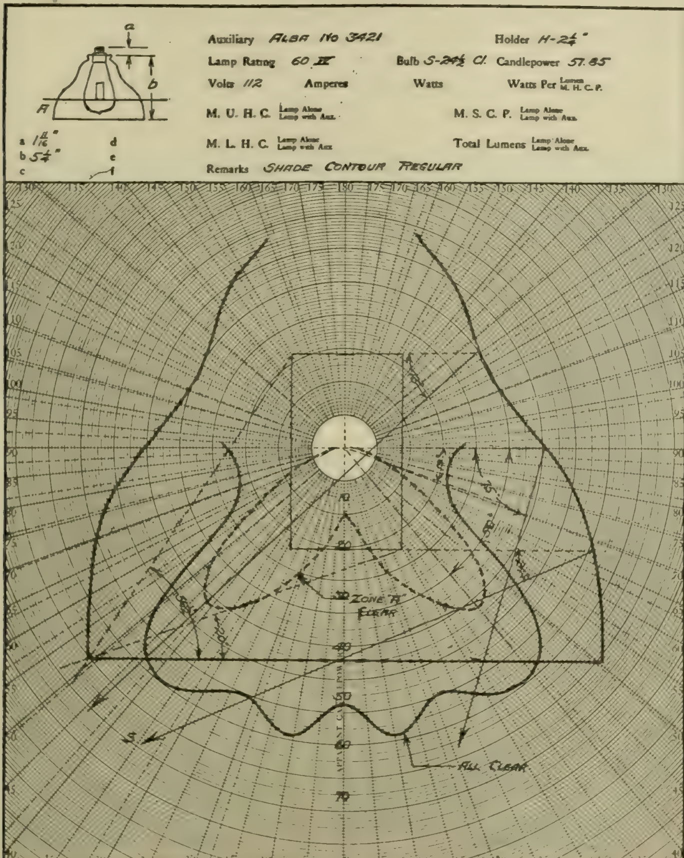

Fig. 29.—I-type characteristics.

The inherent differences in reflecting action have been shown, and a study of the action of the light density opal glass, or diffusely reflecting glass shades had led to the conclusion that a considerable range of control may be obtained with such a reflector.

It is beyond the range of this paper to present a comparison

between old and new designs of shades, and it will be sufficient to state that very material improvements are being made, which are based upon the information previously outlined. Some further investigations are being made to learn the actions of

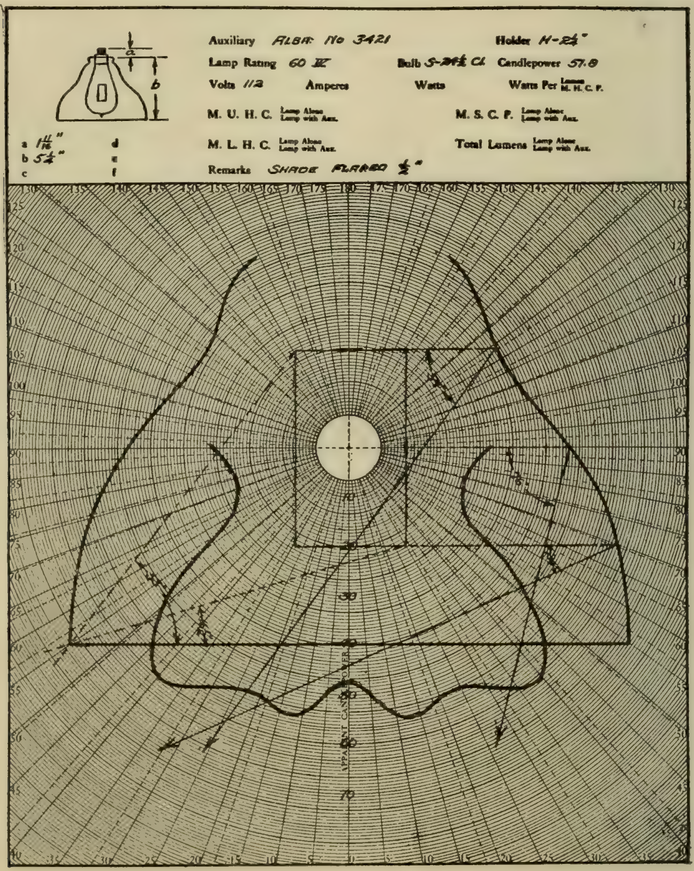

Fig. 30.—I-type characteristics.

various small portions of the lamp filaments. This is done by using a very small miniature lamp, and moving it successively over portions of the position ordinarily occupied by the standard shaped filament.

In general, from a study of the various shapes of shades and their corresponding curves, it appears that—

1. Distributions from this class of shades are controllable.

2. Specular reflection is active to a considerable extent.
3. Diffuse or spread reflection and diffusion are also active.
4. No type or shade exposing the filament at wide angles can be made focusing.

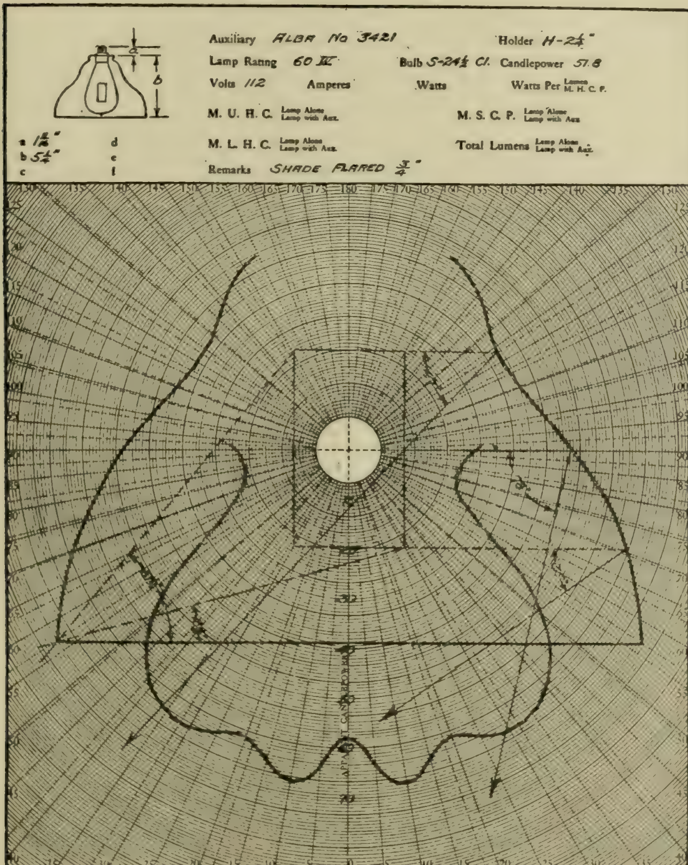

Fig. 31.—I-type characteristics.

5. Downward diffusion occurs from even nearly verticle shade walls.
6. The shade necks are chiefly responsible for 0 deg. angle intensities.
7. Shades of this character of glass may within reasonable limits be extensive or intensive according to design.

Just how the characteristics may be changed can be seen from

Fig. 33, showing practically the same sized shades and identical lamps, but with one unit giving downward reflection that is quite largely specular, and the other giving a downward and lateral diffusion.

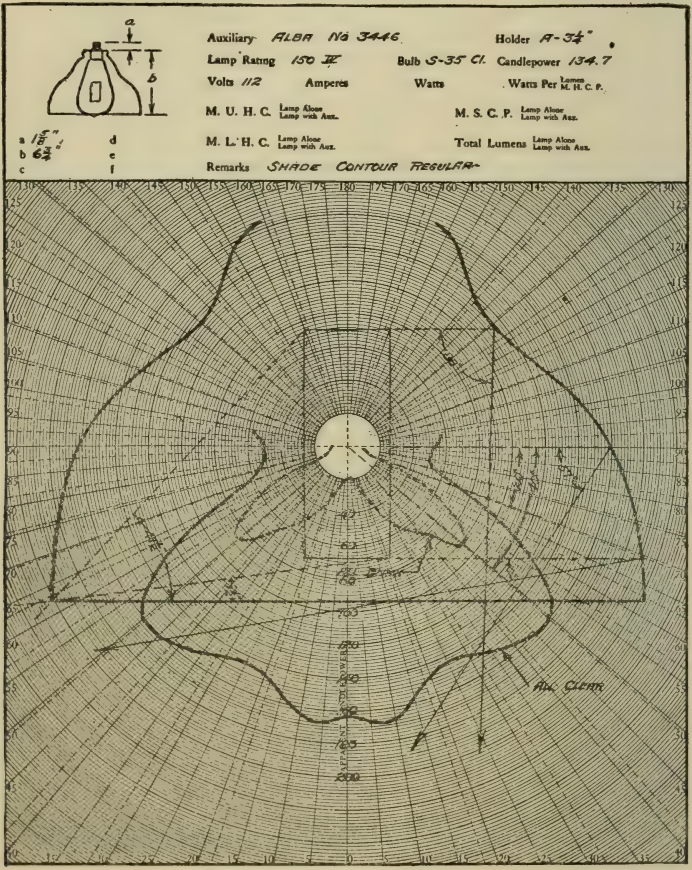

Fig. 32.—I-type characteristics.

Many additional items might be outlined that come directly from the studies herein presented. All of these matters will add to the sum of the available knowledge of correct shade design, and this end certainly justifies the means, even though these means involve much more additional study, analysis, and synthesis than this paper presents.

ABSTRACT OF PAPER—THE ELECTRIC ARC IN VAPORS AND GASES AT REDUCED PRESSURES.*

BY W. A. DARRAH.

Present commercial arc lamps operate with few exceptions in an atmosphere rich in oxygen or the oxide compounds of the electrodes. As a result the electrodes are oxidized as rapidly as they are vaporized (if not already composed of oxides, as in the case of magnetite arc), and as the oxides cannot be used again commercially it is necessary to provide means for disposing of them. This cycle of vaporization and oxidation of the electrodes naturally results in their comparatively rapid consumption, which necessitates the trimming and cleaning of the arc lamp, one of the large factors of arc lamp operation.

The research which is described in this paper was carried on to investigate the possibilities of designing an arc lamp which supplies the arc from a surrounding vapor or gas which would not be destroyed by the arc and, while the results are very promising from a practical standpoint, they are outlined here for their scientific value and should be considered only as a scientific research.

A crude apparatus was arranged in which two hard-carbon electrodes were placed vertically above each other in a tight glass vessel, and an arc drawn between the electrodes. As might be expected, this arc was non-luminous and very unstable. Accordingly, a small amount of carbon tetrachloride was poured into the vessel with a rather marked result. The arc then became stable and could be drawn out to several times the length which was previously possible, although its luminosity was not much increased. Later a more elaborate apparatus was constructed to avoid soot deposits. This consisted of a glass bulb filled with stannic chloride to a pressure of 3 to 4 centimeters of mercury and the direct current arc was drawn between graphite electrodes.

* Abstract of a paper presented before a joint meeting of the Illuminating Engineering Society and the American Electrochemical Society, New York, November 11, 1915. The paper is published in full in the *Transactions* of the American Electro-chemical Society.

These preliminary tests having indicated possibilities as well as having shown the difficulties to be overcome, additional smaller lamps were constructed. With these a detailed study was made of the effects of the various available electrode materials as well as the different vapors and lamp designs. Several kinds of glass, sealing compounds, insulators, and various forms of electrodes and supports were tried. The chambers around the arc were designed to catch the soot after it passed through a draft tube. Due to disintegration and excessive soot the graphite electrodes were given up and finally tungsten was substituted and proved to be practically inert to the action of the surrounding gases.

Further tests were conducted in which the pressure and arc length were varied and a study was made of the characteristics of the arc burning in atmospheres of antimony, phosphorus, and arsenic chlorides. Curves were plotted showing the relation between arc current and resistance per inch of arc length.

Luminosity of the arc, its color and stability were investigated while burning in a long series of compounds. These compounds may be roughly divided into three classes, as follows:

(*A*) The illuminants or those materials which give a high luminous efficiency. They usually produce unstable arcs if used alone.

(*B*) The stabilizers or those compounds which have a low luminous efficiency but when introduced into an arc allow a very stable arc at relatively low voltages.

(*C*) The "catalyzers," or those compounds which are introduced to assist recombination in the flame zone, thus minimizing deposits.

Chlorine was the halogen most generally used, because of the stronger union of the chloride, and the reduced tendency of the dissociation products to attack the tungsten electrodes.

The finished lamp consisted of a containing glass vessel hermetically sealed, the current being carried into the lamp by heavy tungsten wires. The upper electrode is carried on a floating iron core and a magnet coil around the outside of the tube, but in series with the arc, serves to lift the upper electrode automatically to the desired separation and hold it suspended under such conditions that the separation immediately compensates for changes in current value. By the proper dimensions and design of coil

and core, stable operation may be secured without the use of a dash-pot.

To start the lamp it is only necessary to apply current to the terminal. When the circuit is completed the current passes through the electrodes (which are held in contact by gravity), then through the flexible lead to the series coil which it energizes, causing the magnet to separate the electrodes, thus drawing the arc. The arc immediately becomes extremely brilliant although there is a slight increase in efficiency for 10 or 15 minutes, after which the lamp reaches operating temperature and conditions become stable.

It would appear that an investigation along the lines here described would open up new possibilities in light production, but it cannot be too strongly emphasized that while the results set forth in this paper offer considerable promise from an applied, practical standpoint, yet they are not presented for consideration as representing a finished device but merely a research in what seems to be a new and interesting field.

SYMPOSIUM ON CONVENTION PAPERS.*

OUTLINES OF TALKS GIVEN BY ALAN BRIGHT, O. E. ESCHHOLZ AND J. L. MINICK.

Mr. Bright outlined the effect of the European War and the San Francisco Exposition on the production of lamps and accessories in this country. Special emphasis was placed upon the development of flood-lighting and pageant lighting during the last year. He further reviewed several of the convention papers dealing with progress in the manufacture and utilization of improved lighting appliances and glassware. In closing Mr. Bright spoke of the requirements, regulations and legislation governing the use of automobile head-lamps.

Mr. Eschholz reviewed the presidential address of Dr. Steinmetz. It was shown that the ultimate luminous efficiency obtainable from solid incandescent radiators is too low for economical conversion. The high efficiency light source of the future is likely to depend upon the electro luminescence of gases or solids. Recent investigations in this field have uncovered hitherto unsuspected phenomena. By a suitable adjustment of physical conditions the character of radiation as produced by such luminescence can be varied remarkably. By this means, intensities of 100 lumens per watt have been obtained from a quite practical light source and in the case of electro luminescence of fluorescent substances, still higher efficiencies have been secured.

Mr. Minick spoke in general of the nature of the convention as a whole. Later he brought up for discussion the characteristics of the old railway signal systems and the danger in properly reading the signals, due to interference by arcs and other illuminating units. New systems making use of red, yellow and green in place of red, green and white were described. Also the system which depends for its signals entirely on the position of the lamps, making use only of yellow glass, thus avoiding the interference. The importance of the use of the integrating

* This symposium was given before the Pittsburgh Section of the Illuminating Engineering Society, Pittsburgh, Pa., Nov., 1916.

spheres or an equivalent device in the rating of lamps was emphasized, as was the importance of a proper system for rating lamps. The question of uniformity of practice in lamp inspection with the importance of the proper understanding of the best criterion for the use in question was discussed.

TRANSACTIONS

OF THE

Illuminating Engineering Society

NO. 8, 1916

PART II

Miscellaneous Notes

Council Notes.

(A joint meeting of the outgoing and newly elected Councils.)

Date: October 11, 1916.

Place: At the general offices of the Society, 29 W. 39th St., New York, N. Y.

Present: Wm. J. Serrill, L. B. Marks, Preston S. Millar, Geo. S. Crampton, J. Arnold Norcross, Clarence L. Law, A. S. McAllister, C. O. Bond, D. McFarlan Moore and, upon invitation, G. H. Stickney.

The meeting was called to order at 2.15 p. m. by Vice-president Clarence L. Law in the absence of Dr. Charles P. Steinmetz.

The minutes of the regular Council meeting of June 8th were adopted as printed and the minutes of the special Council meeting of Sept. 20th were approved.

Upon recommendation of the Finance Committee, payment of vouchers No. 2616 to 2618 and 2634 to 2649 inclusive, aggregating $1,328.04, was authorized. Mr. Calvert, Chairman of the Finance Committee, presented a written report on the methods of the Society as they affected finances.

An oral report on section activities was given by Vice-president Clarence L. Law, representing the New York Section, and a written report was read from George A. Hoadley, Vice-president, representing the Philadelphia Section.

Dr. A. S. McAllister, Chairman of the Special Committee on Transaction Expense, presented an exhaustive report on the cost of publishing the TRANSACTIONS. This report pointed out the sources of possible error in preparing and adhering to a fixed budget, for this expenditure, over a period of years. Based on the statistics submitted the committee made a number of recommendations for the consideration of the Council.

The report was gratefully acknowledged by the Council and the Committee on Finance was requested to review the recommendations as they affected the latter committee and to submit their recommendations for final action at the next Council meeting.

Dr. A. S. McAllister, Chairman of the Committee on By-Law Revision, recommended a report covering the entire reediting of the by-laws together with certain proposed changes necessitated by the new grade of membership and calculated to more clearly define the spirit of the constitution.

At this time the chair was turned over to President Wm. J. Serrill who continued the meeting and took up the business of the new Council.

Mr. H. Thurston Owens was recommended by the Section Board and approved by the Council as a member of the New York Section Board of Managers, to fill the vacancy made by the resignation of Mr. Edward Wray.

Mr. Geo. H. Stickney was appointed by the Council to the position of General Secretary, made vacant by Professor C. E. Clewell's resignation.

Mr. Serrill submitted a proposed list of the various standing committee chairmen. It was moved and carried that the following chairmen as selected by Mr. Serrill be approved:

Committee on Nomenclature and Standards: A. E. Kennelly, Chairman.

Committee on Papers: P. S. Millar, Chairman.

Committee on Editing and Publication: A. S. McAllister, Chairman.

Committee on Sustaining Membership: J. D. Israel, Chairman.
Committee on Finance: H. Calvert, Chairman.
Board of Examiners: A. S. McAllister, Chairman.
Committee on Section Development: G. H. Stickney, Chairman.
Committee on Progress: F. E. Cady, Chairman.
Committee on Membership: W. A. Durgin, Chairman.
Committee on Lighting Legislation: L. B. Marks, Chairman.
Committee on Research: E. B. Rosa, Chairman.
Committee on Glare: P. G. Nutting, Chairman.
Committee on Reciprocal Relations with Other Societies: C. L. Law, Chairman.
Council Executive Committee: W. J. Serrill, Chairman.
Committee on School Lighting: M. Luckiesh, Chairman.
Committee on Popular Lectures: E. J. Edwards, Chairman.
Sub-Committee on Residence Lighting: E. J. Edwards, Chairman.
Sub-Committee on Store Lighting: A. L. Powell, Chairman.
Sub-Committee on Elementary Lectures: A. J. Rowland, Chairman.
Sub-Committee on Office Lighting: C. E. Clewell, Chairman.
Sub-Committee on Industrial Lighting: W. A. D. Evans, Chairman.

It was further decided that Mr. Serrill in consultation with the chairmen of all committees be authorized to appoint committeemen for the respective committees.

Mr. Serrill announced that in order to facilitate consular action hereafter, he would appoint individual members of the Council to investigate and present definite reports and recommendations on matters to come before the Council.

The following resolution was adopted:

Resolved, That the General Secretary be instructed to express to the General Electric Company the appreciation of the Society for the colored inserts which they so kindly provided in connection with Mr. W. D'A. Ryan's paper in the Edison-Decenial number of the TRANSACTIONS.

It was moved and carried that the regular monthly Council meeting be held at 2.00 p. m. on the second Thursday of each month.

The meeting adjourned at 6.15 p. m.

New Associate Members.

BASSETT, PRESTON R.
Research Dept., Sperry Gyroscope Co., Brooklyn, N. Y.

CALDWELL, JESSE THOMAS
Engineering Dept., National Lamp Works, Nela Park, Cleveland, Ohio.

CURTIS, DARWIN A.
Illuminating Engineer, National X-Ray Reflector Co., 235 W. Jackson Blvd., Chicago, Ill.

HANDY, WALTER K.
District Manager, Potomac Electric Power Co., 231 14th St., N. W., Washington, D. C.

MORROW, W. O.
101 Park Ave., New York, N. Y.

New Members by Transfer.

BURNETT, DOUGLASS
Commercial Manager, Consolidated Gas, Electric Light & Power Co., Baltimore, Md.

GOODENOUGH, FRANCIS WILLIAM
Controller of Gas Sales, The Gas Light & Coke Co., Horseferry Rd., London, England.

SAUNDERS, WM. E.
Engineer, The U. G. I. Co., 1401 Arch St., Philadelphia, Pa.

STAVE, THEODORE
Consulting Engineer, Theo. Stave Co., 30 Church St., New York, N. Y.

Section Meetings.

NEW YORK SECTION

On October 11, 1916, the New York Section participated in a joint meeting with the New York Companies' Section of the National Electric Light Association. The meeting was addressed by Major General Leonard A. Wood on the need for industrial, moral and military preparedness, and by Mr. W. S. Gifford, Supervising Director of the Committee on Industrial Preparedness, on the work of that committee.

In the Auditorium of the Engineering Societies Building, on November 9th, was held a joint meeting of the New York Sections of the American Electro-Chemical Society and the Illuminating Engineering Society. The papers of the evening were by Mr. W. R. Addicks, "Some Notes on Gas Standards," and Mr. Elmer L. Knoedler, "The Most Recent Developments in Incandescent Gas Mantles."

On November 9, 1916, a joint meeting of the New York Sections of the American Electro-Chemical Society and the Illuminating Engineering Society was held in the Engineering Societies Building.

The topic of the evening was "Modern Gas Lighting." Mr. W. R. Addicks, representing the I. E. S., gave a very interesting talk on "Some Notes on Gas Standards." The A. E. S. was represented by Mr. Elmer L. Knoedler, who spoke on "The Most Recent Developments in Incandescent Gas Mantles." Mr. Edward J. Murphy gave an address on "The Chemistry of Modern Illuminating Gas Manufacture."

Preliminary to the meeting, an informal dinner was held at Keen's Chop House, 70 W. 36th St., New York, N. Y.

PHILADELPHIA SECTION

On October 20, 1916, the Philadelphia Section held its meeting at the Engineers' Club. Dr. Enoch Karrer presented the paper of the evening entitled "Illuminating Engineering 100 Years Ago." The paper was illustrated by a few well chosen and effective slides. Prior to the presentation of the above paper, Mr. Henry Hess, of the Hess-Ives Company, gave a short talk on "Color Photography." His interesting explanation was furthered by screening some of the most beautiful color photographs.

The following tentative program for the next few months has been announced:

November 17th—"Color and Fabrics," by Mr. Cox, School of Industrial Art.

December 15th—"The Lighting Schemes of Thomas Jefferson," by Professor W. S. Redman, University of Virginia.

January—"Development of Recent Lighting Fixtures and Accessories," by Messrs. Samuel Snyder and James D. Lee, Jr., United Gas Improvement Co., Philadelphia, Pa.

February—"Flood Lighting," by Mr. L. C. Porter, Edison Lamp Works of General Electric Co., Harrison, N. J.

March—"Indirect Lighting Designs," by Mr. C. H. Swanfeld, National X-Ray Reflector Co., Philadelphia, Pa.

April—"Application of Incandescent Lamps to Photography," by Mr. R. T. Dooner, Philadelphia, Pa.

A meeting of the Philadelphia Section was held on November 17, 1916, at the Engineers' Club, 1317 Spruce St., Phila-

delphia, Pa. Mr. Richard S. Cox, in charge of Jacquard Design, Drawing and Color Department, Philadelphia Textile School, delivered an address on "Color and Its Application to Fabrics," with a demonstration of artificial lights and their effects on clothing and interior decorations, and an exhibit of various wool, cotton, silk fabrics and draperies. Preceding the paper of the evening, Dr. George A. Hoadley of Swarthmore College delivered a short talk and gave a demonstration on the "Fundamentals of Lighting," this being the first of a series of popular elementary lectures prepared by the Society.

PITTSBURGH SECTION

The Pittsburgh Section held a meeting on October 27, 1916. Messrs. J. L. Minick, Alan Bright, and O. H. Eschholz gave a symposium on "Progress in Illuminating Engineering." The program was based on the papers recently presented at the tenth annual convention of the Society.

CHICAGO SECTION

The Chicago Section held a meeting on November 9, 1916, in the Commonwealth Edison Company Building. The paper of the evening was "Growth and Importance of Illuminating Engineering," by Professor Morgan Brooks. Those who took part in the discussion of the paper were M. G. Lloyd, J. R. Cravath, F. A. Rogers and O. R. Hogue.

Personal.

Word has been received that Mr. Walter C. Allen, Electrical Engineer of the District of Columbia, recently entered upon his duties as executive officer of the Public Utilities Commission. He succeeds Major General Julian L. Schley. Mr. Allen was appointed district engineer in 1904 and under his administration the street lighting systems of Washington have been greatly improved. He is a member of the American Institute of Electrical Engineers and of the Illuminating Engineering Society.

Obituary.

Mr. C. Alfred Littlefield, General Secretary for the past two years of the Illuminating Engineering Society, passed away at his home, 72 St. Nicholas Place, New York City, on October 23, 1916. Mr. Littlefield was appointed General Secretary of the Society in October, 1914, and at the end of that fiscal year was reappointed by the Council to fill the same position, made vacant by the resignation of Mr. Alten S. Miller. Throughout his term of office Mr. Littlefield gave untiring effort to the advancement of the interests of the Society. He was known personally to a large percentage of the membership and all join in expressing their sorrow at his early and unexpected removal from a life full of devotion to his home, his family, his business and professional activities.

Mr. Littlefield was born in Philadelphia, Pa., but his early life was spent in Jacksonville, Fla. After living there a number of years he came north, settling in Morristown, N. J., and was later graduated from the Morristown High School. A year after graduation he came to New York, and was employed in the office of a civil and sanitary engineer. He left this position, May 1, 1891, to enter the service of the Edison Electric Illuminating Company of New York, the predecessor of the New York Edison Company. He was connected

first with the underground department, but about six or eight months after coming to the company, he was transferred to the inspection department, and has been connected with that department since, occupying during these years various positions. At that time the historic old Pearl Street station was in operation and much of his work required him to be at this station, but, of course, this did not last long as the station was abandoned shortly afterward. Mr. Littlefield was a charter member of the Illuminating Engineering Society and has been active in various committee work in this Society since its organization. He was a manager of the New York Section in 1909 and 1910 and was elected a director of the Society in 1912. He resigned as a director in October, 1914, to accept the office of general secretary. He was a Class B member of the National Electric Light Association, having joined in 1905, and was secretary of the Commercial Section. He was also a member of the Jovian Order, the National District Heating Association, the Electric Vehicle Association of America, the American Museum of Safety as well as several other civic and national organizations.

TRANSACTIONS
OF THE
Illuminating Engineering Society

VOL. XI DECEMBER 30, 1916 No. 9

EFFECTS OF BRIGHTNESS AND CONTRAST IN VISION.*

BY P. G. NUTTING.

Synopsis: This paper outlines those relations between lighting and good seeing which center upon the psychophysical laws relating perception to the flux density of light at the retina, all other relations between lighting and seeing being simple physical and geometrical optics. Of chief interest at every brightness level are (1) the lowest perceptible brightness, (2) the faintest perceptible contrast, and (3) the highest comfortable brightness. Precise data on threshold, contrast and glare sensibility are given over the whole visual range (from 10^{-6} to 10^{+4} ml.). A new quantity, the discrimination factor, a direct measure of seeing quality, is defined.

At the Washington convention of the Illuminating Engineering Society last September, I presented a general paper on the retinal sensibilities related to illuminating engineering. While the data then presented on visibility and part of the data on photometric sensibility and adaptation was old, a great deal of new data obtained by newly devised methods was presented in the fields of brightness, hue and purity sensibilities, rate of adaptation, size of pupil and the effects of size of field, oblique glare and hue upon the absolute sensibility of the retina. A considerable portion of the data was obtained in the weeks just preceding the convention by Mr. Felix Elliott and myself in order to round out the paper. Since that time Mr. Julian Blanchard has worked continuously with the visual sensitometer then described, and many sets of observations have been taken by Mr. Prentice Reeves and myself as well.

* A paper presented at the tenth annual convention of the Illuminating Engineering Society, Philadelphia, Pa., Sept. 18-20, 1916.

Communication No. 38 from the Research Laboratory of the Eastman Kodak Co.

I wish now to present and discuss some of our best recent results on the reaction of the retina to various degrees of brightness and contrast in the field viewed. Good lighting is that which produces good seeing. The criterion for good seeing is the ability to see detail with comfort and efficiency, detail in highlight or shadow, with bright or dark surroundings, in (relative) motion or at rest. It is the fundamental psychophysical laws underlying these reactions that we aim to clear up. The following table shows how illuminating engineering depends upon the laws of retinal reaction. It is quite analogous to the relation of photography to the laws governing the photographic reaction to light.

TABLE I.—Dependence of Illuminating Engineering on Retinal Reaction.

I. Good Seeing		
Acuity	*Efficiency*	*Comfort*
Contrast in Detail	Seeing: Fatigue	Lack of Fatigue
Definition in Detail	Light Economy	Lack of Injury
	(Related by Psychophysical Laws to)	
II. Retinal Flux of Light		
Intensity	*Distribution*	*Color*
	(Deduced by Optical Laws from)	
III. Objective Brightness and Contrast		
	(Deduced by Optical Laws from)	
IV. Illumination and Reflecting Power of Objects		
	(Deduced by Optical Laws from)	
V. Intensity and Position of Light Sources.		

The various steps are related by comparatively simple optical laws except that between retinal flux and seeing.

DETERMINING THE VISUAL REACTION.

As is well known, the visual *sensation* cannot be directly measured, but its derivative *sensibility* is readily measurable and from this the sensation may be readily deduced just as the scale of an ammeter may readily be reconstructed if the sensibility is known for all currents. Now the retina is an area on which is cast the angular light flux from outside the eye. At any point of the retina the sensibility varies with flux density, time and color, and different parts of the retina differ from one another in sensibility. Further, the retina is strongly vicarious, one part suffering a change in sensibility because a neighbor does. Our

data refers to the sensibility of the center of vision, the fovea, the exposure on surrounding areas being constant, known and stated.

Brightness sensibility may be measured in several different ways: The brightness difference just noticeable in closely adjacent fields (*photometric* sensibility), the lowest brightness perceptible (*threshold* sensibility), the least perceptible difference in two brightnesses alternating in quick succession (*flicker* sensibility) and the brightness just painfully bright, *glare* sensibility.

I. *Threshold Sensibility.*—The instantaneous threshold indicates the state of the retina at any point, at any time, and is in line with the modern photochemical theory of vision. In our apparatus, the eye views a large field of known brightness, then for this field is suddenly substituted another very faint one found by trial to be just visible. The logarithm of the brightness of threshold plotted against the logarithm of the brightness of sensitizing field determines the sensibility curve.

II. *Photometric Sensibility.*—When two adjacent steady fields are just perceptibly different in brightness, this least difference depends partly upon the difference in level and partly upon the steepness of the brightness gradient between the levels. This sensibility is the easiest to measure but not so easily interpretable. The logarithm of difference in brightness as a function of the logarithm of mean brightness determines the sensibility curve.

III. *Flicker Sensibility.*—When the two just noticeably different brightnesses, instead of being steadily side by side, are impressed at the same spot in rapid alternation with no black interval between, conditions are quite simple. At the frequency of maximum flicker there can not be enough adaptation to affect the results and conditions are such as to give a very fair test of the retinal state.

IV. *Glare Sensibility.*—In this case the eye previously adapted to a given known brightness is suddenly exposed to a field just bright enough to appear glaring. Precise measurements cannot be taken by this method but even rough data are of great value. The ability of the retina to withstand an overload is determined by this method.

THE ABSOLUTE SENSIBILITY OF THE RETINA.

The results of very precise determinations of the bright-

nesses which will just produce a sensation are given in Table II and Fig. 1. The eye was sensitized in each case to a certain brightness B by viewing a large white field illuminated to the proper amount. This field was 60 cm. square and viewed from a distance of 35 cm. and was illuminated to intensities ranging from 0.000001 ml. up to 2000 ml. After sensitizing, this light was snapped off and an attempt made to see a small square (30 mm. square) in the center of the large square illuminated from behind. The brightness of this small square was adjusted until it could just be seen at the instant of snapping off the brighter light. This instantaneous threshold T is taken as a measure of the sensibility of the retina when adapted to the brightness of the sensitizing field. Since making our preliminary observations a year ago we have repeated and extended our work using a larger sensitizing field, a more perfect black wedge for controlling intensities and have investigated the effect of size of test field and of using red, yellow, green and blue light.

The values obtained are the following:

TABLE II.

All values are in millilamberts.

Field Brightness	Instantaneous Threshold	log B	log T
0.00000071	0.00000071	—6.15	—6.15
0.00000100	0.00000093	—6.00	—6.03
0.0000100	0.0000042	—5.00	—5.38
0.000100	0.000019	—4.00	—4.72
0.00100	0.000093	—3.00	—4.06
0.0100	0.00039	—2.00	—3.41
0.10	0.00175	—1.00	—2.76
1.00	0.0082	0.00	—2.09
10.00	0.036	+1.00	—1.44
100.00	0.191	+2.00	—0.72
1,000.00	2.140	+3.00	+0.33
2,000.00	3.980	+3.30	+0.60

The data for white light is the mean of that taken by Blanchard, Reeves and myself; the three subjects agree with each other in absolute sensibility to within the uncertainty in a single set of readings. The curve is a straight line except at the ends and with a very slight dip in the region of ordinary brightnesses indicating that there the retina is a little more sensitive than normal. The bending off near the threshold is due to the test field being considerably smaller than the sensitizing field. The falling off

from the linear relation at high intensities is due to failure of retinal adaptation at high intensities. If continued, the curve would cut the 45 deg. line at about 7.1 lamberts, indicating that that brightness is blinding.

GLARE SENSIBILITY.

An attempt was made to directly determine the brightness that would just appear uncomfortably bright with the retina adapted to any given brightness. This was found to be quite a definite

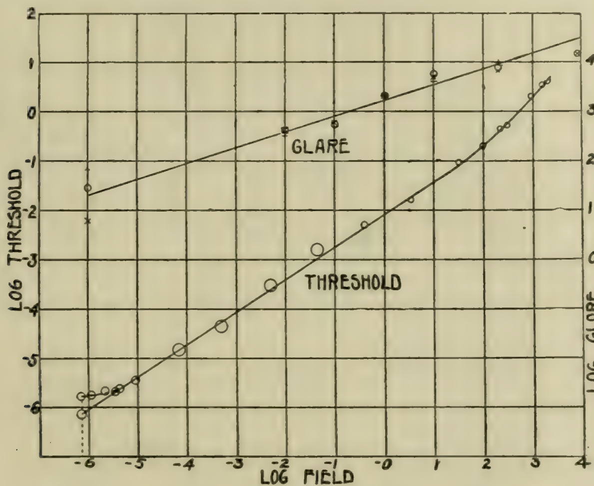

Fig. 1.—Brightnesses which will just produce a sensation of glare.

quantity and moreover the three observers obtained surprisingly concordant data. The result is a linear relation between the logarithm of glare and logarithm of field. The data obtained are given in Table II and the curve is shown in Fig. 1.

TABLE III.—DATA ON LOGARITHM OF GLARE.

Log field	J. B.	P. R.	P. G. N.	Mean	Line
—6.0	+1.81	1.45	0.78	1.35	1.30
—2.0	2.50	2.64	2.65	2.60	2.60
—1.0	3.18	2.74	2.78	2.90	2.90
0.0	3.30	3.30	3.30	3.30	3.23
+1.0	3.62	3.79	3.76	3.72	3.54
2.30	4.00	3.87	3.85	3.91	3.96
2.76	4.06	4.09	4.11	4.09	4.13
3.91	5.02	4.18	4.16	4.45	4.47

If continued the glare line cuts the field line at log B = 4.72

or B = 52 lamberts, about five times as bright as white paper in direct sunlight. At this brightness the field itself appears glaring even with bright surroundings and full adaptation, that is to say, adaptation ceases.

The equation of the glare line is

$$\log G = 3.2 + 0.32 \log B$$

from this $G = 1700\ B^{0.32}$

hence for a rough calculation of the glare limit, take the cube root of the brightness to which the eye is adapted and multiply by seventeen hundred.

DIFFERENCE SENSIBILITY.

The just noticeable difference in brightness in two adjacent fields has been often determined, but with considerable uncertainty, in (*a*) the brightness unit, and (*b*) the time of adaptation; we have made determinations by three different methods using known brightnesses and times of adaptation.

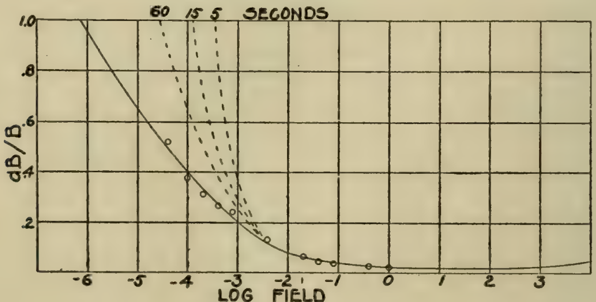

Fig. 2.—Adaptation curves.

König's old data checks with ours provided his intensity unit (which was rather uncertain) be taken as 0.0040 millilambert and provided considerable time be allowed for adaptation. The curves obtained are shown in Fig. 2. The lower curve is for full adaptation.

The three upper curves of Fig. 2 are for 5, 15 and 60 seconds adaptation. Using smaller test spots shifts these curves to the right. The circles represent new data by Blanchard using the bench method. In one of the new methods, adaptation curves are run with the sensitometer using as test spots two slightly different brightnesses in a fixed ratio to one another.

Time of adaptation curves are run with each contrast, giving a series of curves. A cross section of these curves gives the contrasts just visible after a given time. Plotting these just noticeable contrasts as functions of field brightness, we have finally the difference sensibility curve again. The curves of partial adaptation are much steeper at low intensities.

DISCRIMINATION FACTOR.

Good seeing is determined chiefly by the ability to distinguish details differing but slightly in brightness; details in high light, half tone and in shadow. To represent this it was found necessary to invent and define a new term, the *discrimination factor*. This is defined as the field brightness divided by the just noticeable difference, B/dB. This quantity is a direct measure of the power to distinguish details except when large color differences are present. Visual acuity, so called, a mere sharpness of definition, is a minor factor when contrasts are slight.

In the following table (Table IV) are summarized the visual sensitometric data of chief practical interest.

TABLE IV.—VISUAL SENSITOMETRIC DATA.

Field Brightness	Difference Fraction	Discrimination Factor	Threshold Limit	Glare Limit ml.
0.000001	(1.00)	1.0	0.00000093	20.1
0.00001	(0.66)	1.5	0.0000042	40.7
0.0001	0.395	2.5	0.000019	89.0
0.001	0.204	4.5	0.000087	186.0
0.01	0.078	12.8	0.00039	400.0
0.1	0.0370	27.0	0.00174	810.0
				l.
1.0	0.0208	48.2	0.0081	1.66
10.0	0.0174	57.5	0.036	3.47
100.0	0.0172	58.1	0.28	7.25
1,000.0	0.0240	41.7	2.15	14.45
10,000.0	(0.048)	(20.9)	(232.0)	30.90

Field, threshold and glare brightnesses are in millilamberts. These data are plotted in Fig. 3 as logarithmic ratios. The X axis is the line of equality; ordinates represent sensibility. The four crossed ordinates indicate the four chief lighting levels; mean exterior daylight, interior daylight, lighted interiors at night and streets at night.

Running up the ordinate of any field brightness, the inter-

section with the threshold curves indicates absolute sensibility, the least brightness visible; the intersection with the glare curve, the brightest that can be viewed; while the discriminant shows what constrasts are visible in the middle tones of best vision. The diagram will repay careful study.

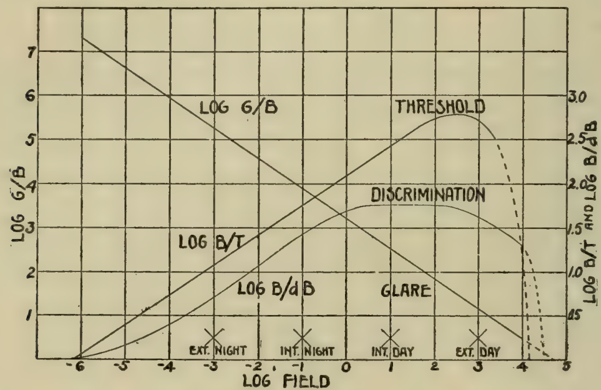

Fig. 3.—Field, threshold and glare brightness.

SUMMARY.

The glare brightness has been directly measured by three subjects adapted to field brightnesses from 0.000001 to 10,000 ml.

The logarithm of glare is a linear function of the logarithm of field over the whole range.

Logarithm of threshold is a linear function of logarithm of field from the absolute threshold up to 100 ml.

Values of least perceptible difference have been redetermined by three different methods in established brightness units and its variation with the size of field and time of adaptation shown.

A new quantity (the discrimination factor, B/dB), which is a direct measure of seeing quality, has been defined and calculated for the whole visual range of brightnesses.

The visual processes at the upper limit of vision have been outlined.

APPARENT BRIGHTNESS; ITS CONDITIONS AND PROPERTIES.*

BY LEONARD THOMPSON TROLAND.

Synopsis: This paper is a discussion of brightness from the psychological and physiological points of view. Visual response is analyzed into successive stages, and the relations of apparent brightness with the "intensity factors" of these stages are considered. The measurement of the retinal image, the laws of variation of the sensitivity and selectivity of the retina for brightness, the Purkinje effect, and intensity factors in the optic nerve conduction are considered in the light of new experiments. On experimental grounds, the thesis is defended that brightness sensitivity as expressed by the ordinary "visibility curve" rests upon a single physiological process, which is independent of the mechanism of color perception. This proposition is applied to the problems of heterochromatic photometry, in conjunction with the results of new measurements dealing with the methods of direct comparison and of flicker. The conceptions underlying the definition of "light" are analyzed from the point of view of the psychologist.

The ultimate problems of illuminating engineering are psychological in nature.

There is a certain vagueness in this statement, because at the present time a disagreement exists among psychologists as to the exact definition of their science. If we adopt the point of view of the "behaviorists," we must say that the ultimate problem of the illuminating engineer is to produce visual stimuli which will enable human organisms to adapt themselves with the greatest efficiency to their environment. If, on the other hand, we take the standpoint of the "introspectionists," we will assert that the object of illuminating engineering is to generate certain desirable forms of *visual experience* in the *consciousnesses* of human individuals. In other words, the final goal of lighting technology is clear seeing, eye comfort, and beauty.

The Analysis of Visual Response.—The object of the present paper is to discuss some of the conditions and properties of one aspect of visual consciousness, namely, *apparent brightness* or

*A paper presented at the tenth annual convention of the Illuminating Engineering Society, Philadelphia, Pa., Sept. 18-20, 1916.

luminosity. By apparent brightness is meant the brightness of any object of vision, exactly as it *appears* to a given observer. This quantity is often called brightness sensation, but the term is somewhat misleading, because luminosity is a property of external objects, as we see them. In the last analysis, it is not radiation, but apparent brightness, properly graduated and distributed over our visible environment, which it is the function of illuminating technology to create.

Luminosity, as a psychological quality, has often been identified with *whiteness.* This view is made plausible by the clearly antithetical character of luminosity and *blackness,* and is in closer harmony with the facts than are theories which attribute a *specific brightness* to the color qualities.

Although the apparent brightness of objects, for any observer, certainly does not *reside* in the observer's brain, there is hardly a doubt that it does *depend* completely upon physiological processes which are occurring there. Hence, if we are to understand its conditions, we must take into consideration not only the radiation which is impinging upon the eye, but all of the physiological events which intervene between the impact of this radiation and the generation of the consciousness of light. Some of the relations involved in this problem are the most remarkable known to science.

The apparent brightness of any object depends (1) upon the spatial distribution—in each wave-length—of the radiant energy reaching the cornea of the eye from the object; (2) it depends upon the "speed," and allied properties, of the eye—regarded as a camera—which determine the illumination of any point on the retina; (3) it is a function of the sensitivity of the retinal receptors to radiation of various wave-lengths; (4) of the relation between the retinal process and the excitation of the optic nerve fibers; (5) of the character and efficiency of the nerve conduction to the brain; and (6) apparent brightness is a function of the excitation of the ultimate receivers in the cerebral cortex, and of their interaction. It is possible that still another stage must be added, that of psychical influences exerted wholly in the field of consciousness.

The seven stages of visual response indicated above, follow each other in time in the order given. The nature of each stage

depends partly upon that of the preceding one, but also upon important conditions peculiar to itself. Accordingly, the final stage, visual consciousness, cannot be completely determined from a knowledge of any single preceding stage, except possibly the cerebral brain-process. The problems of visual research consist entirely in the analysis of visual response into such physiological stages; the separation of the variables making up each stage; and the determination of the laws connecting these variables, first, with other variables in the same stage, and, second, with the corresponding variables of the immediately preceding stage.

In each stage of the visual process there must exist what may be called an *intensity factor.* In the case of the stimulus, this factor is *radiant power;* in the case of consciousness, it is *luminosity.* I shall try to trace out, schematically, the relations of this psychological intensity factor with other variables of the response, especially with other intensity factors, and with *color;* quite neglecting, however, one very important condition, *viz., contrast.*

The extent and accuracy of our knowledge of the stages of visual response is in inverse proportion to the intimacy of their relationship with consciousness. Concerning the primary stimulus, *i. e.,* the radiation striking the eye, we are fairly well informed. With regard to the intra-ocular adventures of this radiation we know a little; concerning retinal response, very little; and concerning the visual brain process practically nothing.

The Measurement of the Retinal Image.—We must thank Helmholtz and his contemporaries for their accurate analysis of the dioptrics of the eye, but we must regret that neither Helmholtz nor any of his successors has worked out in detail many factors required for a deduction of the quantitative constitution of the *retinal image* from a knowledge of the radiation entering the eye. I have found it possible to make a list of nearly thirty such factors, the majority of which have not been measured even roughly. For example, what are the laws of the scattering of light in the eye? How much light is transmitted through the eye-wall under different conditions of illumination? How does the illumination of the retina by a given object vary with the angle of view? What are the laws of fluorescence of the various ocular

media, including the retina? It is only recently that such a simple problem as that of the axial chromatic aberration of the eye has been thoroughly investigated (Nutting), and our knowledge of the selective absorption of the human eye is still largely inferential.

It is of especial importance in connection with these intra-ocular problems that we should possess methods applicable to living individuals, since the individual variations are undoubtedly large. At the present time I am attempting to develop means for accomplishing this end, (1) for the scattering of light, and (2) for selective absorption and fluorescence, making use among other devices, of an adaptation of Helmholtz's ophthalmoscope.

The failure of visual investigators to concentrate upon these intra-ocular problems is largely due to their neglect of the fact that it is the *retinal image* (considered spectrophotometrically) which constitutes the actual physiological stimulus to vision. This lapse is evident in the crude inattention to the influence of *pupillary size,* and change of size, upon visual phenomena, which characterizes most of the work done in this field. Since neglect of the pupil may lead to an error as great as 1,600 per cent. in the specification of the intensity of the stimulus, I have in my own investigations invariably made use of an artificial pupil of known area. I have also found it very convenient to express all intensity measures in terms of a unit of retinal illumination which I have called the *photon.*[1]

At the present stage of our discussion, however, it is desirable to express intensities in terms of units of radiation rather than of light, because, strictly speaking, light is not the stimulus to vision, but is vision itself. If I is the radiant analogue of the photometric brightness (in the direction of the eye) of a stimulus surface, and if i is the analogue of retinal illumination, calculation yields the following formula:[2]

$$(1) \qquad i = 0.00416 \frac{p\, t\, d^2 \cos \phi}{(d - x)^2} I + A,$$

[1] A *photon* is that intensity of illumination upon the retina of the eye which accompanies the direct fixation, with adequate accommodation, of a stimulus of small area, the photometric brightness of which, as determined by the standard flicker comparison and a normal subject, is one candle per square meter, when the area of the externally effective pupil, considered as lying in the nodal plane of the eye, is one square millimeter. The intensity of a visual stimulus, expressed in photons may be called its *physiological intensity.*

[2] i is expressed in watts per square meter; p, in square millimeters, d and x in centimeters and I in watts per steradian per square meter.

where p is the area of an artificial pupil at a distance x from the nodal plane of the eye, t is the transmission of the whole eye for the type of radiation under consideration, d is the distance of the stimulus surface from the nodal plane, ϕ is the angle between the normal to the pupil and the line of sight, and A is a correction factor embracing the effects of scattering, fluorescence, etc. This provides us with an expression for the intensity factor of any point in the retinal image, in terms of the intensity factor of the corresponding point in the visual object, and what, probably, are the most important ocular conditions.

Retinal Sensitivity for Brightness.—The next stage in the response is the excitation of the retina. The exact mechanism of this action is still a matter of speculation, but there are a number of assumptions which may be considered well-established. In the first place, there are two independent retinal processes, those of the rods and of the cones, respectively, the effects of which are combined in consciousness. Secondly, the response is photochemical, depends on molecular or atomic resonance, and probably involves changes in the degree of ionization of substances contained in the receptors. These latter statements are based upon the study of the visual purple, upon the electrical phenomena exhibited by the eye and upon the general properties of radiation and matter.

The same considerations also furnish the basis of the following statements. The selective response of the eye to radiation of different wave-lengths (visibility curve) depends principally upon the photochemical selectivity of the retina. Adaptation, or the general change in sensitivity to radiation of all wave-lengths, is conditioned by a change in the *concentration* of the light-sensitive substances in the retina. If we represent the concentration in question by s, the coefficient of selectivity by m $[=f(\lambda)]$, and the intensity of the retinal responce by q, we can write:

$$q = m\,s\,i \tag{2}$$

where i has the same significance as in (1). The majority of theories of retinal action regard q as a rate of decomposition of the sensitive substance, such that

$$-\,ds/dt = m\,s\,i. \tag{3}$$

At least schematically, this equation represents the theory of

Hering, and it obviously demands that constant stimulation of any single portion of the retina should finally result in complete exhaustion of the visual process, *i. e.,* that vision should be self-destructive.

I have carried out elaborate experiments to test this conclusion, and have found it not to be generally true, either of brightness or of color-vision. Prolonged fixation of a visual stimulus results in the reduction of its apparent brightness towards an asymptotic value, but when sufficiently high intensities are employed this value is never zero, or a neutral mid-gray. The value is higher the greater the intensity of the stimulus, and for intensities less than about 6 photons (with a 1¼ degree foveal field) lies below the threshold.

I have suggested the use of the term *minuthesis* in describing this depression of sensation under the influence of a stimulus, to replace the misleading word, "fatigue."

Psychologists have long taken great interest in the "fluctuations in visibility" exhibited by objects viewed under appropriate conditions. My experiments show clearly that for intensities higher than about 6 photons, with a dark background, these fluctuations are due to the spontaneous contractions and dilations of the pupil. They are absent when an artificial pupil is employed.

It is evident that the simple photo-chemical theory of response must be amplified so that a new supply of sensitive substance will be constantly available for vision. This can be done by assuming a *repair process, a,* according to the equation:

(4) $$a = r - c\,s$$

where r and c are constants, so that

(5) $$ds/dt = r - (c + mi)\,s.$$

If we work out the consequences of this latter equation in accordance with the principles of chemical mass action, we arrive at results at least qualitatively in harmony with the facts.

For example, we find that the change in sensitivity of the retina under the influence of radiation should follow the law:

(6) $$s = \frac{1}{b}\left(r + e^{-b(t+k)}\right)$$

where $b = c + mi$, and k is a constant. This law is certainly of the right general form.

The value of the retinal response intensity for *equilibrium* with a stimulus of intensity, i, is given by the equation:

$$q = \frac{r\ m\ i}{c + m\ i} \tag{7}$$

Analysis shows that this relationship accounts qualitatively not only for Fechner's logarithmic law of the relation between stimulus and response, which has been proven to hold for the electrical currents of the retina, but also for the upper and lower deviations from this law.

However, the results of a quantitative test of our simple photochemical assumptions are less satisfactory. I have attempted such a test in connection with the laws of duration of negative after-images under special conditions. A negative after-image is merely a local reduction in the apparent brightness of a visual object, occasioned by preëxposure of the corresponding portion of the retina to radiation. If the time of preëxposure is x and the duration of the after-image is y, the following equation can be deduced from our assumptions:

$$y = \frac{1}{b} \log_e \left(\frac{1 - e^{-bx}}{b\,\Delta s}\right) - k \tag{8}$$

where Δs is the threshold for discrimination of differences in retinal sensitivity. It can be shown that if S is the slope, for a given value of x, of the curve which this equation represents, then:

$$b = -\frac{1}{x} \log_e \left(\frac{S}{S + 1}\right) \tag{9}$$

b should be constant, for all values of x. From an actual set of measurements, I found: for $x = 8$ seconds, $b = 0.096$; $x = 32$, $b = 0.0287$; $x = 128$, $b = 0.0140$; $x = 256$, $b = 0.0114$. (See Fig. 1.)

Given a sufficiently long exposure, the visual system reaches a *state of equilibrium* with respect to any stimulus which may be acting upon it. By estimating the value of the asymptote approached by y in the experimental curve corresponding to equation (8), I have attempted to determine for various stimuli the time required for the retina to reach a condition just indistinguishable from that of equilibrium, starting from equilibrium

with darkness. I found that it varies a great deal between individuals and with the size of the test field, but that for a given individual it is nearly independent of color, and between 10 and 500 photons, is practically independent of intensity. For myself, using a 1¼° foveal field the *equilibrium time* ranges from 70 seconds in the red to 95 in the violet. It would seem advisable to carry out the majority of visual measurements under conditions of at least approximate retinal equilibrium.

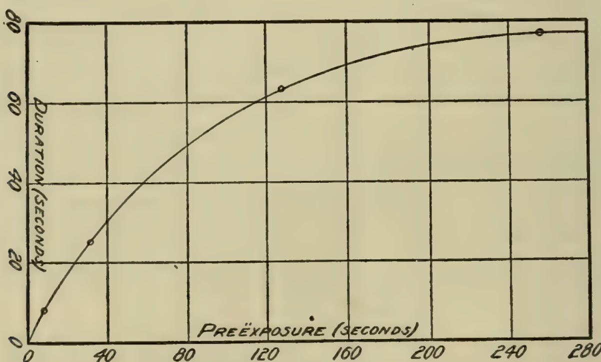

Fig. 1.—The relation between the duration of a negative after-image and the exposure which produced it.

Another quantity of interest in this connection is the least time required to produce a noticeable negative after-image. I have made a protracted series of measurements to determine this value, and for an intensity of 150 photons and a 3⅓° field, I find it to be approximately 0.050 second, independent of the wave-length of the stimulus. This shows the extreme rapidity with which the sensitivity of the retina decreases during the first instants of exposure to radiation.

With an intensity of 40 photons, I found the total decrease in one minute to be to 0.27 of the initial value, and with an intensity of 1,500 photons, to about 0.03, in the same time.

Retinal Selectivity For Brightness.—Thus far we have devoted our attention to the variable, *s*, as one of the principal determinants of apparent brightness. However, there is another, of perhaps greater importance, namely, *m*, of equation (2). This quantity varies with the wave-length of the stimulus, and upon

its value must depend, primarily, the so-called *visibility* of the radiation in question.

In accordance with the "duplicity" or rod-cone theory of retinal function, it is necessary to suppose that both s and m represent, in general, the sum of two independent quantities, one for the rods and one for the cones. There is thus a rod sensitivity and a cone sensitivity, a rod visibility and a cone visibility. At intensities below about 0.05 photon, only the rods are functional, while above 60 photons, and in the fovea at all intensities, the cones alone are active. The relative inactivity of the rods at high intensities cannot be explained on a simple photochemical theory of adaptation, and is probably due to a physiological interruption of their process. In general, it may be said that we know more about rod than about cone sensitivity, but more about cone than about rod visibility. From the standpoint of illuminating engineering, this latter circumstance is perhaps unfortunate, since the problems of illumination are by no means confined to cone vision.

The average visibility curves obtained by Nutting and Ives apply to the cones. A remarkable feature of these curves is their degree of symmetry. Since the cones are the organs of color vision, it should be expected that their visibility curve would show a number of maxima, corresponding with the several color processes, as postulated, for example, by the Young-Helmholtz theory. An examination of Nutting's curve shows that its slight lack of symmetry consists in a depression of the blue side, but that it offers no suggestion of multiple baxima.

The visibility curve was established, like all other photometric relationships, by an equation of apparent brightnesses. Owing to the complexity of the conditions determining this latter variable, such an equation cannot be regarded immediately as a criterion of the equality of intensity factors in any other stage of the response. As a first step in ascertaining the significance of the visibility curve for the retinal process, it would seem necessary to correct for the *selective transmission of the eye.* This transmission, including that of the ocular media and of the yellow spot is given in Fig. 2, and the influence of the correction upon Nutting's visibility curve is shown in Fig. 3. The resulting *ret-*

inal visibility curve is almost perfectly symmetrical, and fits the simple probability function,

(10) $$v = e^{-0.0002705\,(\lambda - 554.9)^2}$$

much more closely than the uncorrected empirical curve fits Nutting's asymmetrical function.

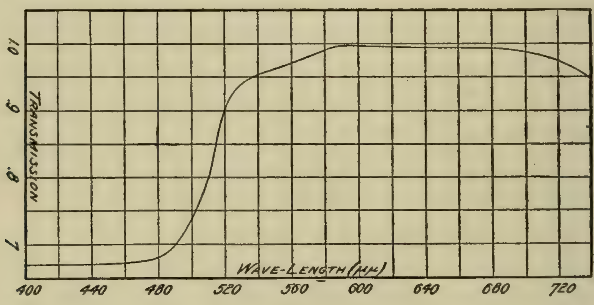

Fig. 2.—The transmission of light of different wave-lengths by the eye, from the cornea to the sensitive layer of the retina.

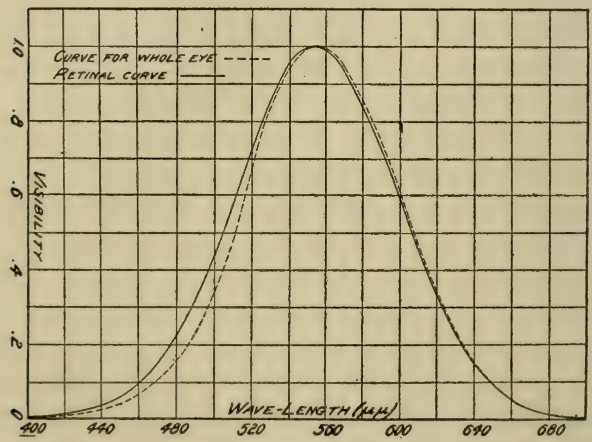

Fig. 3.—Nutting's visibility curve, and the effect of correcting it for the selective transmission of the eye.

This striking symmetry of the cone visibility curve leads almost inevitably to the inference that *luminosity is due to a single photochemical process in the retina,* and is not to be attributed to a summation of the response intensities of three or more color

processes. Attempts to work out the consequences of this latter hypothesis, by Abney and by Ives, have led naturally to the conclusion that practically all of the luminosity is contributed by one color factor, which is not physiologically probable. A more reasonable view lies in the original assumptions of Hering's theory, which identified luminosity with whiteness, and postulated a single, independent process for white, having a maximum in the middle of the spectrum.

Other evidence for the independence of the processes underlying apparent brightness of those underlying color, can be found. I have already mentioned the similarity of the laws governing luminosity minuthesis for different colors. I have made thousands of measurements on these phenomena under many conditions, and am not convinced that the wave-length of the stimulus has any effect upon the retinal process for luminosity, although I have definitely sought for such a relationship. According to McDougall, the "action time" or time required for a stimulus to produce a maximum luminosity is independent of color, although a function of luminosity. The independence of critical flicker frequency of color and its dependence on brightness is familiar to everyone. Visual acuity is probably a function of luminosity alone, given equal definition of the retinal image in the various colors. It is also probable that the luminosity contrast effects of different absolute luminosities do not depend upon concomitant color or color differences. According to König, the just noticeable difference in brightness, at a given absolute intensity, is independent of color; and Ives has shown that the summation of brightnesses is not affected by color differences. Recently, at the suggestion of Dr. E. P. Hyde, I have carried out a series of measurements upon the influence of minuthesis due to radiation of one wave-length, upon the apparent brightness generated by radiation of another wave-length. For example, suppose that we preëxpose adjacent areas of the retina to a red and a blue of equal luminosity, and then suddenly replace the blue by a second red of the same physical intensity as the first; at the first instant after the substitution, will the apparent brightnesses of the first and second reds be equal? Experiments of this sort upon two subjects using all possible combinations of four spectral colors at high and low intensities

failed to reveal differences in luminosity much greater than a threshold value. In other words, the reduction in luminous sensitivity of the visual system depends only upon the luminosity of the acting and reacting lights and is independent of their color.

Purkinje Effects.—All of the above statements concerning the independence of luminosity phenomena of color are valid only with reference to the cone process in isolation from the activity of the retinal rods. In other words, they should hold for the rod-free central region of vision, and at intensities above 60 photons. Under other conditions, either the rods are functioning alone—in which case color vision is absent—or else the two processes are combined, so that apparent brightnesses and their properties are the expression of two discrete sets of physiological quantities, the relative degrees of participation of which depend upon absolute intensity, wave-length, and the position of the image on the retina.

The *Purkinje and allied effects,* depending upon the transition from cone to rod vision, are of considerable importance for the illuminating engineer, because they must be considered in the definition of light units, and in the standardization of photometric methods. The consensus of opinion among physiologists has been that the increase in the relative visibility of blue light, as compared with red, which occurs with a lowering of the absolute intensity (and adaptation) for large fields of vision, is absent when vision is confined strictly to the center of the retina. However, Hering has recently claimed that if proper precautions are taken, it can be demonstrated here, also. I have repeated Hering's experiments, employing the precautions which he recommends, and some which he neglected, and have found that in the direct comparison of a red of 654-687$\mu\mu$ with a blue of 469-481$\mu\mu$, there is absolutely no trace of the Purkinje effect in an accurately fixated 1 degree field.

The measurements of Ives show that with the method of flicker, a *reverse Purkinje effect* exists with large fields. I have made determinations of the relative visibility of radiation of wave-lengths 500$\mu\mu$ and 650$\mu\mu$, in comparison with a tungsten standard, at intensities ranging between 0.8 photon and 51.2 photons using a 1° field. I found no satisfactory evidence of a difference in the relative values obtained by the two methods.

If we accept these results, we may feel justified in making measurements of cone visibility at any absolute intensity, down to the threshold, provided a foveal field is employed.

Neural and Cerebral Intensity Factors.—When we pass from a consideration of the intensity factors of the retinal process, and their relation with apparent brightness, to the next stage in the response, the mechanism of conduction in the optic nerve, we find our ignorance to be practically complete. It is quite certain that the nerve impulse consists of an ionic disturbance, and that the proper stimulus of nervous tissue is a difference in electrical potential. I am attempting at the present time to work out some of the details of the hypothesis that the retinal rods and cones are *electrolytic concentration cells,* closely similar to the electric organs of certain fishes, the difference in potential between the two ends of the cell depending upon a difference in the amount of light absorbed.

There can be little doubt that important variables influencing apparent brightness exist in the path of conduction between the retina and the brain. This is proven by many facts of binocular vision, such as retinal rivalry, Fechner's paradox, etc. It is probable that color and brightness are communicated to the brain by separate aspects of the nerve process, and that *apparent color* is much more susceptible to modification by nervous conditions than is apparent brightness. This is suggested by many phenomena of color perception, color contrast, and color blindness. It is also borne out by the remarkable fact that the visibility curve of the cones in the periphery of the retina is the same as that of the foveal cones, although in peripheral vision we are all totally color blind.

Many peculiar phenomena can be demonstrated for which the theory of retinal action offers no immediately obvious solution. For example I have discovered that a momentary dimming of the stimulus field upon which a faded negative after-image is projected, brings back the contrast with remarkable vividness. On the other hand, when the field is brightened, the contrast is momentarily *reversed,* so that the preëxposed area is more luminous than the other. It can be shown that both of these effects accompany a readjustment of equilibrium of the visual system, and disappear when equilibrium is reëstablished, and I have

found the hypothesis that they are due, not to retinal factors but to processes in the optic nerve synapses, to be a very plausible one. Recently I have obtained a very clear demonstration that the *reversal effect,* at least, depends upon color, being easily produced in the red end of the spectrum, and practically absent in the blue.

I believe that, with time and patience, all of these relationships can be cleared up by the use of quantitative methods of analysis, and with sufficient attention to physiology and physical chemistry. The same can be said of the relation between the final brain synergy and consciousness itself, although here we reach problems which probably transcend pure physics.

Apparent Brightness and Definitions of Light.—Up to recent times the science of light was regarded as a strictly physical subject. At present, it will be admitted that the problems of radiation and its production are purely physical, but it is now clear that light and radiation are different conceptions, although the former involves the latter. Light is radiation "evaluated according to its capacity to produce" apparent brightness, and the problem of apparent brightness and its relations belongs to psychology and psycho-physiology. To my thinking, the definition of the lumen should be considered to involve a new dimension, ψ, which is the most important one in everybody's experience, although it is absent from the C. G. S. system.

Equal quantities of *light* are quantities of radiation such that they generate in the average, normal, visual system equal degrees of apparent brightness. The ultimate criterion is the judgment upon consciousness, even for the physical photometer. As we have seen, the determinants of conscious luminosity constitute a very complex and heterogeneous collection of variables. The average visibility curve is a summary of the connections which they establish between radiation and apparent brightness, for the very special, convenient, conditions in which photometricians are now primarily interested.

Several considerations regarding this curve are worthy of emphasis. In the first place, it is a statistical or biometric construction, which represents *typical* trichromatic human vision, but does not necessarily accurately describe the vision of any concrete individual, since all individuals vary at least slightly

from the average. Accordingly, it is almost as important to determine the *coefficients of variability* of visibility for radiation of various wave-lengths as to determine the visibility itself. Secondly, if light, in the ordinary sense, is defined in terms of the visibility curves of Nutting or of Ives, then other varieties of light may be supposed to exist. For instance, another form of light could be defined in terms of the visibility curve of the retinal rods. We might call this *twilight* to distinguish it from ordinary light. Its "mechanical equivalent" would be quite different from that of the ordinary variety.

The unit of light is now defined in terms of a peculiar and arbitrary standard, the radiation from a particular 4-watt carbon lamp. The value of the mechanical equivalent of light is scientifically significant principally as a record of the accidental choices of illuminants by our ancestors. However, now that the visibility curve is established, it would be possible to redefine the unit of light upon a rational basis, by setting the mechanical equivalent equal to unity, so that at the maximum of the curve, measures of light and radiation would be quantitatively identical. This device of definition would be applicable to light of all varieties.

Owing to the uncertainty which exists at the present time as to the identity of the results furnished by different methods of photometry, it would seem necessary to include in the definition of light a specification of the photometric procedure to be employed. The values furnished by the "flicker" method are undoubtedly the same as those obtained by "direct comparison," when color differences are absent. Consequently, and on account of the far greater accuracy of the flicker method for *heterochromatic* photometry, it would appear advisable to define light in terms of the results of flicker equations. Homochromatic photometry is, after all, only a very special case of photometry in general.

Some Problems of Heterochromatic Photometry.—Since the entire science of light rests upon the equating of apparent brightnesses, the psychological study of the conditions of the establishment of such equations is of great importance. *A priori,* two primary methods for the comparison of two brightnesses suggest themselves: either (1) they may be presented at

the same time in different spaces, or else (2) they may be presented in the same space at different times. The first method is that of so-called direct comparison, the second that of "flicker." So far as brightness is concerned, the two methods are not fundamentally distinct. The flicker method establishes an "equality of brightness," just as surely as does the method of simultaneous comparison. The only question is as to whether succession in time and juxtaposition in space modify the effects of a given pair of stimuli in the same way.

For every problem concerning the flicker method there is a completely analogous problem with regard to the method of simultaneous comparison, and doubts as to the validity of the results obtained by the two procedures ought to be about equal. For example, if color difference affects the relative rate of growth of two luminosities, through successive contrast, it is also true that the same difference may alter the relative luminosities of two adjacent photometric fields through simultaneous contrast. The flicker method eliminates the direct influence of wave-length difference upon consciousness, while the procedure of direct comparison greatly enhances it.

However, the facts which have been considered in this paper regarding the independence of luminosity phenomena of color, tend to support the view that contiguity in neither space nor time will affect the apparent brightness produced by given stimuli, under identical conditions of retinal sensitivity and selectivity. If all luminosity rests upon a single process, the rate of rise of luminosity, and the minuthetic effect, should be independent of color, as my experiments, in general, prove them to be.

The influence of color, in photometry, consists essentially in the obscuration of luminosity differences rather than in their production; in other words, a color difference raises the discrimination threshold for apparent brightness. I have measured this effect upon the threshold for a large number of combinations of spectral stimuli, the results being given in Table I. A maximum of color difference raises the threshold by a factor of four or five, as compared with the value in the absence of color difference.

The table presents heterochromatic discrimination values for two subjects, T and L. ΔI is the fractional threshold; v is the

TABLE I.

Standard color	Comparison color, $\mu\mu$. 693	670	640	610	580	575	550	520	505	490	475	460	430
Red, 693 $\mu\mu$													
ΔI (T)	0.042	0.080	0.092	0.149	0.170	0.194	0.185	0.190	0.214	0.191	0.195	0.191	0.172
(L)	0.047	0.076	0.085	0.111	0.122	0.135	0.135	0.161	0.144	0.139	0.199	0.154	0.126
v (T)	0.014	0.024	0.028	0.041	0.049	0.052	0.045	0.037	0.040	0.044	0.062	0.036	0.048
(L)	0.016	0.020	0.024	0.027	0.030	0.032	0.045	0.046	0.026	0.044	0.028	0.042	0.045
$\Delta I/S$ (T)	1.00	1.93	2.22	3.58	4.09	4.65	4.44	4.58	5.15	4.58	4.68	4.60	4.20
(L)	1.00	1.59	1.79	2.33	2.57	2.85	2.85	3.41	3.04	2.94	4.21	3.26	2.58
$\Delta I/v$ (T)	2.99	2.94	3.35	3.64	3.49	3.73	4.10	5.08	4.99	3.88	3.14	4.97	3.26
(L)	2.89	3.70	3.51	4.09	4.08	4.27	2.97	3.49	5.47	3.20	7.12	3.65	2.70
Yellow, 575 $\mu\mu$													
ΔI (T)	0.150	0.169	0.175	0.155	0.097	0.037	0.125	0.126	0.185	0.161	0.201	0.191	0.160
(L)	0.199	0.156	0.144	0.104	0.052	0.028	0.080	0.125	0.148	0.196	0.147	0.156	0.109
v (T)	0.038	0.031	0.041	0.043	0.023	0.010	0.035	0.026	0.041	0.057	0.042	0.032	0.046
(L)	0.066	0.047	0.039	0.040	0.013	0.008	0.029	0.037	0.030	0.039	0.060	0.043	0.026
$\Delta I/S$ (T)	4.07	4.57	4.75	4.20	2.64	1.00	3.40	3.43	5.00	4.37	5.45	4.97	4.54
(L)	7.22	5.67	5.23	3.76	1.91	1.00	2.91	4.55	5.38	7.12	5.36	5.66	3.90
$\Delta I/v$ (T)	3.93	5.38	4.25	3.58	4.25	3.78	3.54	4.88	4.46	2.75	4.79	6.33	3.66
(L)	2.84	3.29	2.72	2.59	3.97	3.65	2.80	3.40	4.88	5.00	2.47	3.65	4.13
Green, 505 $\mu\mu$													
ΔI (T)	0.192	0.172	0.155	0.153	0.160	0.173	0.144	0.122	0.037	0.116	0.159	0.147	0.145
(L)	0.231	0.213	0.206	0.184	0.172	0.103	0.117	0.055	0.024	0.079	0.072	0.149	0.107
v (T)	0.044	0.039	0.041	0.038	0.039	0.044	0.029	0.029	0.009	0.028	0.032	0.035	0.036
(L)	0.037	0.026	0.028	0.046	0.040	0.033	0.035	0.019	0.004	0.024	0.019	0.038	0.042
$\Delta I/S$ (T)	5.22	4.69	4.23	4.16	4.35	4.71	3.91	3.32	1.00	3.17	4.33	3.99	3.97
(L)	9.73	9.00	8.69	7.75	7.24	4.54	4.93	2.31	1.00	3.32	3.04	6.28	4.52
$\Delta I/v$ (T)	4.36	4.39	3.76	4.02	4.15	3.96	4.80	4.25	3.88	4.15	4.93	4.18	4.06
(L)	6.28	8.23	7.30	4.04	4.30	3.08	3.38	2.83	6.64	3.33	2.77	3.91	2.55
Blue, 475 $\mu\mu$													
ΔI (T)	0.173	0.176	0.178	0.131	0.128	0.118	0.129	0.129	0.126	0.121	0.075	0.174	0.181
(L)	0.164	0.178	0.183	0.157	0.095	0.141	0.103	0.100	0.134	0.067	0.062	0.080	0.104
v (T)	0.039	0.060	0.053	0.034	0.046	0.030	0.036	0.046	0.056	0.033	0.013	0.045	0.029
(L)	0.059	0.030	0.046	0.028	0.027	0.030	0.018	0.025	0.062	0.010	0.013	0.023	0.027
$\Delta I/S$ (T)	2.31	2.35	2.38	1.75	1.71	1.58	1.72	1.72	1.68	1.62	1.00	2.32	2.42
(L)	2.66	2.88	2.97	2.54	1.55	2.27	1.67	1.62	2.17	1.07	1.00	1.31	1.68
$\Delta I/v$ (T)	4.45	2.94	3.35	3.89	2.47	3.98	2.96	2.82	2.24	3.72	5.58	3.87	6.30
(L)	2.80	5.91	4.02	5.63	3.49	4.73	5.65	4.01	2.16	6.65	4.91	3.42	3.91

average of the mean variations of the points determining the threshold, also expressed as a fraction of the absolute intensity. $\Delta I/S$ is the threshold in terms of the homochromatic threshold as a unit; and $\Delta I/v$ is the ratio between the threshold and the average mean variation of its determining points. Each value for subject T represents from 40 to 100 independent observations, and for subject L, 20 observations. In the average for both subjects, $\Delta I = 4v$. This work was done at an intensity of 25 photons, with a 1 by 2½ degree field.

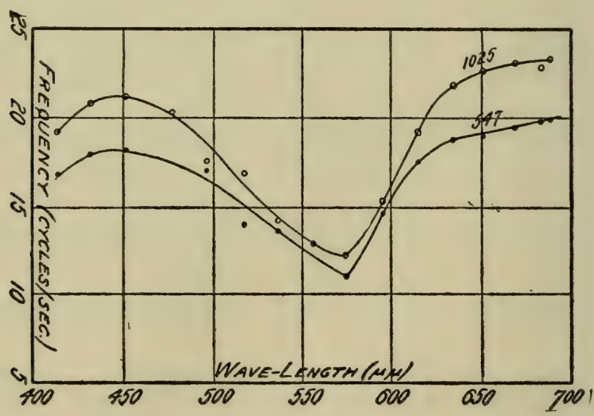

Fig. 4.—Flicker photometer frequency as a function of wave-length for two intensities.

An analogous problem in connection with the flicker photometer concerns the speed at which the stimuli must be alternated in order to just eliminate the flicker due to color difference. I have made measurements of this *flicker photometer frequency,* over the entire spectrum, at intensities ranging between 6.4 and 1,650 photons, and with standards of several tints. The spectral curves obtained with a "white" standard at 1,025 and 547 photons are shown in Fig. 4. It will be seen that the curve is a regular one, having a single minimum at about 575 $\mu\mu$. A considerable alteration of the color tone of the standard changes the position of the minimum only slightly, so that it seems very probable that the curve depends upon the *inherent saturation* of the spectral colors, at equal luminosity. I have also found that for all spectral stimuli, the relation between flicker

photometer frequency, f, and absolute intensity, i, follows an equation of the form

$$f = b\, i^a, \tag{11}$$

where b and a are constants which vary with the wave-length.

The addition of white light to a saturated spectral color decreases its flicker photometer frequency very slowly. The curve for red is given in Fig. 5.

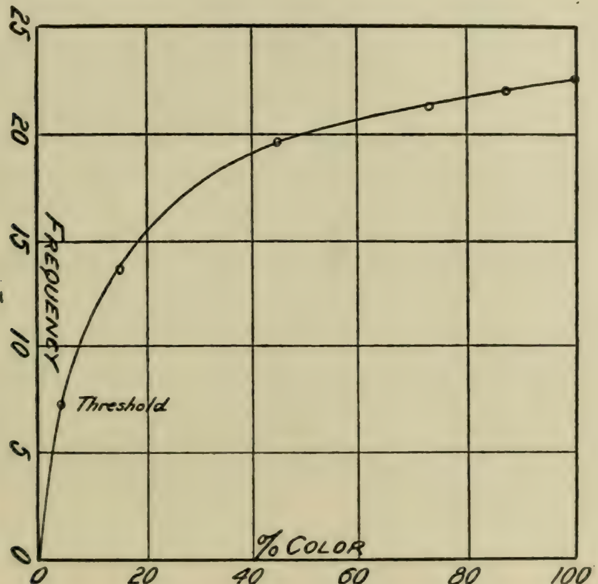

Fig. 5.—Flicker photometer frequency as a function of the physical saturation of a color (spectral red, 670, at an intensity of 230 photons).

The curve of flicker photometer frequency against wave-length bears a very suggestive resemblance to a reciprocal of the visibility curve, somewhat skewed in the direction of the yellow. If luminosity depends upon a single physiological process, and if this single process is identical with that underlying the quality, *whiteness*, this resemblance is exactly what should be expected; in other words, the inherent saturation of the spectral colors ought theoretically to conform inversely to the visibility curve. It is possible that the standard employed in my measurements was somewhat yellowish, which might explain the skewing of the

curve. The second depression of the frequency, in the violet, can be accounted for by scattered light in the instruments or by fluorescence in the eye.

The experimental and theoretical studies reported in this paper must be regarded primarily as starting points for further work. The realm of visual phenomena is overfull of opportunities for fascinating investigations, which can be carried out with an amount of effort very small compared with that necessary for advance in many other lines. There are problems here which have troubled the human mind for centuries. Some of these are philosophical, but I believe that they are all practical. Vision is the principal medium through which our minds come into contact with the outside world, and there is almost no human activity which does not depend for its success upon clear seeing. Moreover it is among visual stimuli that the artist finds his most fruitful materials. If by the application of quantitative methods to the study of these questions, we should finally be able to place the knowledge of visual processes upon a truly scientific basis, there can be little doubt that upon this knowledge, could be founded a technology of good seeing which would be by no means the least among the branches of engineering science.

DISCUSSION ON PRECEDING PAPERS BY DR. NUTTING AND DR. TROLAND.

M. LUCKIESH: I am sure that I look forward with interest to the future contributions which will come from Dr. Troland's researches. The most interesting point of Dr. Troland's paper to me is the promise that it holds out for ultimately simplifying visual problems by separating the color and brightness factors.

WARD HARRISON: I should be interested to know whether in its application to street lighting Dr. Nutting's table gives us anything more than the limits of brightness which are tolerable to the eye; in other words, with a field brightness of 1/1000 millilamberts is to be expected that one could see objects beyond a source having a brightness of 186 millilamberts without difficulty or simply that this light would not be uncomfortably bright?

F. C. CALDWELL: It seems to me that this field of work, this relation of illumination to the functioning of the eye, is the most promising field of activity in the science of illumination. This work is somewhat difficult for those of us who are not psychologists to follow, and we shall have to do some hard studying to fully appreciate it. There is one feature of this curve that is certainly of great practical interest, that is the horizontal portion, where the seeing is equally good between about 1 millilambert and 1,000 millilamberts. It would be interesting if Dr. Nutting would give us some idea of the relation between these degrees of brightness and the corresponding foot-candle illuminations.

J. R. CRAVATH: In applying the glare limit in millilamberts which is given in the right-hand column of Table IV, we should bear in mind the conditions under which the glare was observed. In other words, it applies to a brightness which the observers instantly recognize as glare causing annoyance. A much lower brightness contrast would cause eye fatigue were the eyes subjected to it for hours at a time. In other words, if we would take this glare limit column and apply it to the lighting of our offices, for example, we might select bowls that would give us eye fatigue in the long run, although they might not appear very bright to us at the start. This should be observed in the practical application of a table of this kind. As a practicing engineer, I want to

express appreciation of the work that Dr. Nutting and these other gentlemen are doing along this line, and we will do what we can to try to connect up the practical with the scientific after they have worked out the data.

LEONARD T. TROLAND: With regard to the unit which I called the photon, which involves multiplying the photometric brightness of the surface, expressed in candles per square meter, by the effective aperture of the pupil in square millimeters, I have found this very convenient myself, but I admit what Dr. Nutting says, that the ultimate expression should be in terms of the flux density at the retina. However, the photon unit does not require so much mathematics, and I have been interested primarily in helping the psychologists, many of whom are studying vision somewhat at random, and often without any satisfactory control of the intensity of the stimulus, to be a little bit more exact. Of course it is better to reduce the statement of the intensity to lumens per square centimeter on the retina, but if it is expressed in photons, which can be done very simply, the other reduction can be carried out by anyone who desires to go into the further refinement.

Concerning Dr. Nutting's equations of the photo-chemical action in the retina, they are undoubtedly more complete than mine. The equations which are presented in my paper are entirely schematic. I wished to state the relations as simply as I could, merely to show that there is a qualitative coincidence between the results deduced and those found. I have myself experimented with a large number of much more complicated expressions, and the trouble is, as Dr. Nutting says, that these are usually not integrable. They are almost impossible to deal with, but if one could manipulate such equations, probably more satisfactory results would be obtained. However, I believe that the qualitative verification of the simple equations shows that the photo-chemical theory of vision is on the right track. It is also borne out by the recent discussion, mentioned by Dr. Nutting concerning resonance and the form of the visibility curve.

C. E. FERREE: Dr. Nutting has been engaged for some time in determining retinal sensitivities and has presented a part of his results to this Society. One of his objects in this work has been to compare the sensitivity or responsiveness of the eye to the different wave-lengths, tested under the same conditions; and

another to make a comparison of sensitivities for approximately the same range of wave-lengths (mixed or white light) under different conditions. In the opening sentence of the present paper, he says: "The retinal sensation cannot be directly measured, but its derivative sensibility is readily measurable." In regard to this statement and the work which it introduces it may do no harm to point out here that sensibilities are not so readily measurable as the statement might seem to imply. That is, if the sensibility of the retina is to be measured in a way that is comparable with the measurement of the sensitivity of the physical recording instruments, two conditions must be fulfilled: (*a*) the amounts of response (sensation) in terms of which the comparison is made must be numerically comparable; and (*b*) the amounts of stimuli used in arousing the response must also be commensurable or numerically comparable. I would like to ask Dr. Nutting whether he considers that threshold or just noticeable differences in sensation are as amounts of response numerically comparable. The sensitivity of two galvanometers could not be compared, for example, were it not known that the divisions on the scales of each were either equal or commensurable; but it is not generally conceded that thresholds and just noticeable differences are as sensation quantities either equal or commensurable. In short, even if the second of the conditions noted above as essential to a determination of sensitivity be disregarded and we consider only the first, we are, it seems to me, confronted with a situation somewhat similar to that which obtains in heterochromatic photometry. That is, in general five different quantities are being used in the work of measuring sensitivities (the liminal threshold, the just noticeable difference, the average error, equal amounts of response, and equal sense differences), and only the last two of these conform to the requirement considered absolutely necessary in determining the sensitivity of a physical instrument. Moreover, in the absence of sureness of principle in case of the other three, two of which are used by Dr. Nutting in the work of this paper, the empirical check of agreement in result with those which have the needed sureness of principle has never been made; yet sensitivities are determined just as if the condition did not exist, comparisons are made, and conclusions are drawn. Nor, passing to the second criterion, do I believe that

Dr. Nutting could say that his stimuli have been treated in terms which are commensurable. Instead then of agreeing with him at once that "sensibility is readily measurable" one is constrained to say rather that its measurement is in some cases by no means easily accomplished, and that while he has given us here results in which thresholds and just noticeable differences appear as quantities of response and in which the stimuli are treated photometrically, he has in reality not made a determination of sensitivities at all unless one grant a different set of methodological standards for the determination of the sensitivity of the retina and the physical instruments. In short, what I wish to call attention to here is the looseness of thinking and practice that prevails more or less generally with regard to the work of determining sensitivities on the physiological side. The work should be revised on the basis of standards set for the physical instruments, and with all of the interchecking of methods that is needed, and the term sensitivity (or sensibility) with its definitely quantitative connotation should be abandoned in all cases in which this standard cannot be lived up to.

Dr. Nutting states that concordant results were obtained in the work on glare sensitivity. I should like to inquire what their criterion of discomfort was in this work. In our own work on determining the comparative tendencies of the different conditions of lighting, etc., to produce ocular discomfort, extending over a period of five years, we have found it absolutely necessary to select some very definite and particular criterion of discomfort if results at all reproducible are to be obtained. Discomfort due to glare is, I scarcely need to point out, a rather widely varied experience. For moderately high intensities of light and short exposures it may be, for example, merely the unpleasantness of an over-strong visual sensation, non-localized and unaccompanied by any uncomfortable or painful sensations in the eye or its surroundings; while for higher brilliancies and longer exposures the visual sensation may be accompanied by definitely localized sensations in the eye, face, or head which have a fairly definite order of succession as the exposure is prolonged. With regard to just what is meant by "uncomfortably bright" in this work, Dr. Nutting's paper leaves us quite in the dark; nor is any value given to the mean error of the determination. It would have

been helpful in the evaluation of the results both of this and the former paper if data had been given that would have indicated at least the order of magnitude of the mean error of the work.

Dr. Nutting speaks of a new term, the "discrimination factor." I can see neither the need nor the philosophy of creating such a new term. The quantity considered seems to be nothing but the Fechner fraction inverted for the purpose of being re-introduced into physiological optics—a subject already much too full of terms about which there is not complete agreement. Moreover, $\frac{dB}{B}$ as originally formulated by Fechner, seems to me a more fitting measure of discrimination than its reciprocal $\frac{B}{dB}$. In the same paragraph, in showing the need for the new term he speaks of visual acuity as meaning "merely the sharpness of definition" of the image on the retina or the resolving power of the refracting media of the eye. This, I scarcely need to point out, is quite at variance with the etymology of the term and with its generally accepted meaning and use. While it was permissible and to the point, although far from new, to indicate in the paper that something besides sharpness of definition of image on the retina is important to clear seeing, little is gained, so far as one can see, by confusing the term which is applied to clear seeing in its totality with a term which connotes only sharpness of definition of image. That is, visual acuity is an expression which is used to cover the net resultant of all the factors which contribute to clear seeing, and these factors include besides sharpness of definition of image on the retina Dr. Nutting's discrimination factor and the space functioning of the retina. No ophthalmologist has to my knowledge ever used visual acuity as synonymous with the resolving power of the refracting media of the eye, nor has he failed to recognize, because of his neglect so to use the term, the importance of retinal sensitivity to clear seeing. The error in Dr. Nutting's definition of acuity, however, can be made clearest perhaps by a simple illustration. An emmetropic eye with a hemorrhage at it fovea would have a negligible or very low power of clear seeing, and yet since there has been no impairment in the sharpness of definition of the image on the retina, there

should be in such a case, according to his definition, no impairment of acuity.

As for the general scope and important bearing of the work that is being done by Dr. Nutting and his colleagues, I can only reiterate by commendation of last year.

P. G. Nutting: I quite agree with Professor Ferree's criticism that the related phenomena which he mentions should be investigated. The data here presented refer to the effect of white light on the foeva. Threshold, difference and glare sensibilities should be determined for the periphery of the retina as well as for the fovea. They have already been determined by Mr. Blanchard for red, yellow, green and blue light. Other possible factors in sensibility mentioned by Professor Ferree, such as the previous treatment of the eye, pupillary effects, attention, fatigue, and the like have all been considered, the data given referring to what in our judgment are the properties of the average normal eye under average conditions. Various observers we find agree as closely as two sets of observations by the same subject agree with each other. However, we considered it advisable to determine the fundamental relations first, leaving related effects, largely of psychological interest, for further investigation.

In the response of the retina and nerve centers to light, at any given brightness level there are three and but three points on the sensation scale capable of direct measurement; the least brightness visible, the greatest brightness tolerable, and the lowest perceptible contrast. The totality of these points for all brightness levels constitute the three sensibility curves given. The integrals of these curves, not given here to avoid confusion, constitute the fundamental sensation scales desired, that is, the visual reaction corresponding to each value of the light stimulus. We consider these data well established for three subjects and in our opinion the resultant curves for the average normal eye will lie very close to those here given.

Replying to Mr. Harrison and Mr. Cravath, I would state that the criterion for glare sensation is by no means so uncertain as one would think. The three experienced observers made no attempt to influence one another's judgment and the data show how well we agreed on the first (and only) set of observations. Our glare limit is that which appears most definite as a sensation.

It lies well above that regarded as perfectly tolerable under steady conditions in interior illumination and far below the glare of ordinary street lighting units and automobile headlights.

In the matter of visual acuity, I disagree with Professor Ferree. I maintain that our ordinary perception of detail is accomplished largely by differences in brightness and to only a slight extent by sharpness of definition in outlines.

Professor Caldwell raises the question of units. Referring to Mr. Cravath's carefully prepared table; foot-candles (apparent lumens per square foot) multiplied by the factor 0.00108 are reduced to lamberts (apparent lumens per square centimeter) so that a foot-candle is 1.08 ml. I may add that a magnesium oxide surface, illuminated by 10 sq. mm. of freezing platinum (Violle standard) at 1 meter, viewed through a pupil of 1 sq. mm. (König's standard) is equivalent to 0.0040 ml. viewed through a 1 sq. mm. pupil. The corresponding flux density at the retina is 0.0144 lumen per sq, mm. When 1 ml. is viewed through a 1 sq. mm. pupil the light flux at the retina is 0.400 lumen per sq. mm.

Our data refers to the natural pupil since it is probably of greater practical usefulness in that form. We have determined the size of pupil corresponding to each brightness viewed so that the data given may be readily translated into data relating to a fixed area of pupil. Our curves and the glass wedges with which they were determined may be seen over at the exhibition. These curves will appear in a more general paper to be published soon.

Referring to Dr. Troland's paper, I wish first to express my deep gratification that someone else has entered this important field of investigation and has contributed so much to our knowledge of the subject in a single paper. I do not agree with Dr. Troland that it is necessary or even advisable to introduce such a unit as the "photon" into visual sensitometry. I consider it preferable to express this fundamental data in terms of flux density at the retina. Now flux density at the retina depends upon two and but two factors: the brightness of the object viewed and size of pupil. Given these, the flux density at the retina, in lumens per square millimeter, may be obtained at once by using the numerical factor just given.

Dr. Troland's mathematical theory is very interesting and his

equations connect the fundamental facts in a simple manner. I wish to point out, however, that they are but special cases of the general photo-chemical reaction equation

$$\frac{dn}{dt} = M\,(N - n) - c\,(l - e)^{-kn}.$$

This equation has not been published because it cannot be solved by direct integration. If it can be solved by any means, it will connect all the fundamental relations in vision; the relation between brightness and luminosity, rate of adaptation, etc., while visibility is a wave-length parameter contained in the constants M, c, and k.

It is extremely interesting that the connection of the visibility curve for absorption in the eye media gives a symmetrical probability curve as Dr. Troland shows. Visibility data were first formulated in a curve of this symmetrical type, ten years ago, and with the same values of the constants. Prof. Houstoun has recently published in the Proceedings of the Royal Society a mathematical theory of the visibility function. This is a reasonance theory and results in a symmetrical function. If the data give a similar function, Houstoun's theory will have a very strong foundation indeed.

Leonard T. Troland: My paper has not seemed to arouse very much discussion, possibly because it is too theoretical. Dr. Nutting's paper of course has a more immediately practical bearing upon the problems of illuminating engineering. He is interested in measuring the direct relations between certain factors which are obviously concerned in every day vision. My own interest is a little bit more analytical, involving an attempt to trace out the probable mechanism of vision and to explain the various empirical relations studied in such work as that of Dr. Nutting, which I am sure that I esteem very highly.

One point I wish to emphasize again and that is what appears to me to be the primary importance of the psychological factors for the illuminating engineer. The object of the illuminating engineer is to produce certain results in consciousness, and if he has no facts upon which to base an idea of what results ought to be produced, he is and should be at sea. This was illustrated somewhat in the discussion yesterday with regard to motion pic-

tures. The problem in this field reduces to the question of what brightness we *desire* on the screen, and the answer seems to be in doubt. Until it is given, other efforts may perhaps be useless.

I shall be interested to see whether the assumptions laid down in my paper for the photo-chemical theory of vision, will suffice to explain some of the new relations which Dr. Nutting has presented. I am not sure whether or not this will be the case. It has occurred to me that his "glare sensation" may possibly be conditioned by the production of a certain degree of contraction of the pupil. A powerful contraction of the pupil is disagreeable, and it is probable that the degree to which the pupil contracts is determined by the amount of retinal response, which of course depends upon the state of adaptation of the retina. A very similar relation would of course obtain for the "instantaneous threshold."

With regard to the problem of measuring "sensation," *i. e.*, what I have called "apparent brightness," it would seem to me that the question as to whether the discrimination threshold can be taken as a unit of sensation, that is, whether it has the same value at all absolute luminosities, is really not so much a question of fact as of definition. It has been said many times in the history of psychology, that sensation, or quality, cannot be measured. This may be true from a certain point of view, but it also may be possible to define arbitrarily conventions for measuring quantities of this sort. One such convention may consist in taking the integral of the sensitivity as the value in question, which would seem to be a perfectly logical proceeding.

A STUDY OF THE ECONOMICS OF OFFICE BUILDING LIGHTING.*

BY SAMUEL G. HIBBEN.

Synopsis: Study is made of the lighting of typical offices by different methods, including various sizes of units and types of equipment. Consideration is given to the wiring, fixtures, upkeep and other details of service. The rental value of offices as affected by natural and artificial illumination is dealt with. A number of curves and charts are included showing the effects of different types of shades, of different hanging heights, etc., on the intensity of illumination. The costs of several sample installations are compared from the standpoint of economy in installation and operating costs.

The modern sky-scraper office building of to-day, peopled with thousands of tenants and managed by competent executives, is verily a city within a city. It has its problems of transportation, its corps of "white wings," its central station, and its departmental government. Its economies of operation are indirectly shared by thousands of persons and, as it improves its service, it affords to each inhabitant safety, speed, health, comfort and luxury. Its one object is to surround the twentieth century business man with the most modern facilities for intercommunication and labor, and personified its motto would be "Ich Dien."

That the success of the large office buildings of recent years is due in no small measure to the economical application of electricity to its transportation, its intercommunication, and its artificial lighting problems, is a generally accepted fact.

We have seen, for instance, the buildings rise higher and higher in proportion to improvements in elevator design. We have seen the growing demand of tenants for telephone service, ventilation, the operation of small machinery, heating, ice-water, cleaning—all of which have been met promptly, or anticipated by the building manager on account of the continued advance in the applied science of electricity.

* A paper presented at the tenth annual convention of the Illuminating Engineering Society, Philadelphia, Pa., Sept. 18-20, 1916.

And now comes the problem of artificial illumination, a problem calling for a more exact solution than most other lighting problems, inasmuch as in the large office building any expense or any saving, however minute in the individual unit, will be multiplied thousands of times and appear upon the records as a large part of the total operating expense.

With the exception of steam heat, probably no one item of expense responds so readily to the efforts of the manager to economize as does that of artificial lighting. As to the general progress in the economics of office building lighting, consider first the following figures. Building A is 10 years old, with obsolete lighting arrangements and accessories. Building B is a modern sky-scraper, giving better illumination for equally long hours:

TABLE I.

	Building A	Building B
Kilowatt hours per year per sq. ft. of floor area	0.92	0.60

Or take again a third representative building, using power for lighting as follows:

TABLE II.

Year	Kilowatt hrs. per year*
1911	78,492
1912	62,940
1913	43,920
1914	46,112
1915	40,500

* Nernst lamps were in use in 1912. Tungstens replaced these in 1912-13. Many type "C" Mazdas were installed in 1915.

Unquestionably, there may be certain economies practiced in office building lighting that appear directly on the expense records. Not so concrete, but equally certain are those economies, which though not always a decrease in operating expense, result in better quality and quantity of illumination; in pleased tenants; and finally, for the owner, in a better scale of rentals, and a higher interest on the investment. Some of the results of studies of office lighting economics are discussed in the following pages.

A. Flexible Arrangement of Outlets.—Starting with the planning of a large office building, one of the first possible economies may be realized by a careful location of outlets. This planning

is more important in office buildings than in other structures, such as stores or factories, because of the necessity of providing arrangements, (1) to centralize power feeders, and have all main and branch circuits accessible, and (2) to anticipate sub-division of office space, and allow for the most flexible arrangements of different illuminated areas per unit.

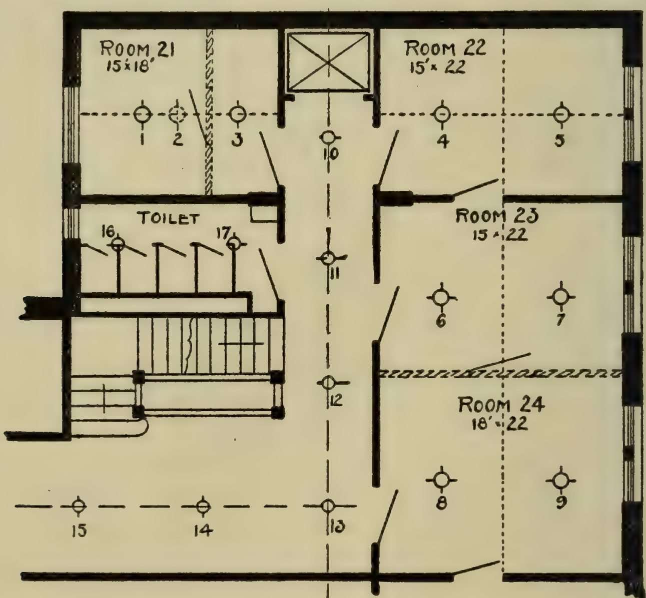

Fig. 1.—In office building of short term leases.

Naturally, it is advantageous to group the long, vertical runs of feeders in a shaft, and place this shaft at the "center of gravity" of the lighting load of the average floor. It is also virtually impossible to change long runs of branch circuits where, in fire-proof construction, the conduit is laid in concrete beneath marble or fine wood-work. The economic use of copper at the present high market price, for these low voltage circuits becomes of great importance, and careful attention should be given to arrangements of balanced feeder circuits.

The second necessity, proper location of outlets for future space sub-division may be illustrated by reference to Fig. 1. The section of the floor that is shown is of a typical high office build-

ing of recent construction. Some years ago, there would have been one central ceiling outlet in each room, but consider, for instance, room 21 if equipped with unit No. 2 only. Should the tenant desire a partition to be placed as shown, which is a not uncommon sub-division, the single unit would not be well placed for the larger and useless for the smaller space. Outlets Nos. 1 and 2, placed as shown would overcome this difficulty. Similarly rooms 23 and 24 taken together, or if divided, may be well lighted. The tendency in modern construction is to be liberal with ceiling outlets in business offices, both for the reasons above mentioned, and to secure more illumination at the room edges than is possible from the one central fixture.

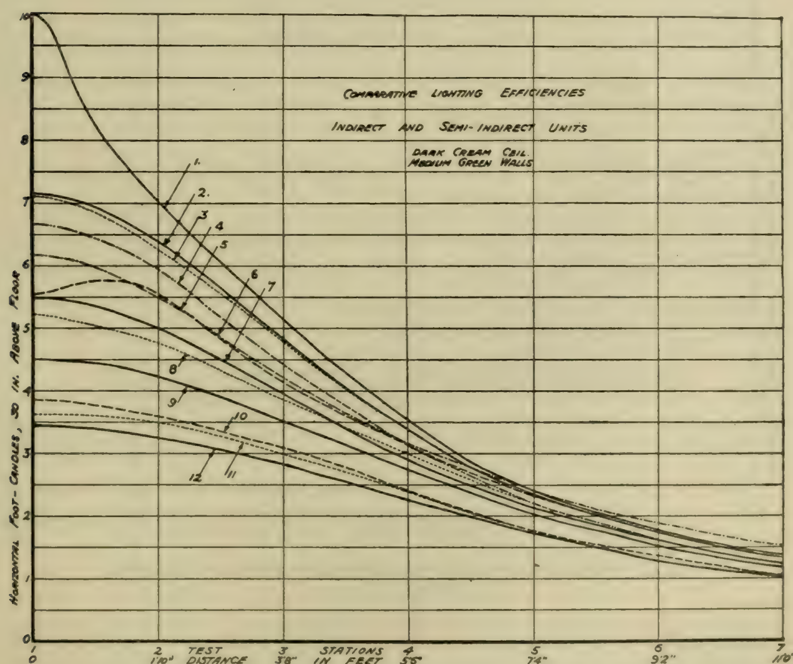

Fig. 2.—Illumination curves showing differences between units of the inverted bowl type.

B. Choice of Fixtures and Glassware.—The glassware and fixtures should be chosen under the supervision of an expert, but unfortunately this is often done by those without experience in

lighting problems. How great may be the difference in intensity of illumination from different shades and reflectors is shown by Figs. 2 and 3. Such tests as are recorded by these curves were all made by the same observer and instruments, in the same size and finish of room, and with the same hanging height from ceiling to lamp filament. All glassware was cleaned and all the various units were stock samples. These were such well recognized units as are individually recommended by the respective manufacturers as the most efficient for office lighting.

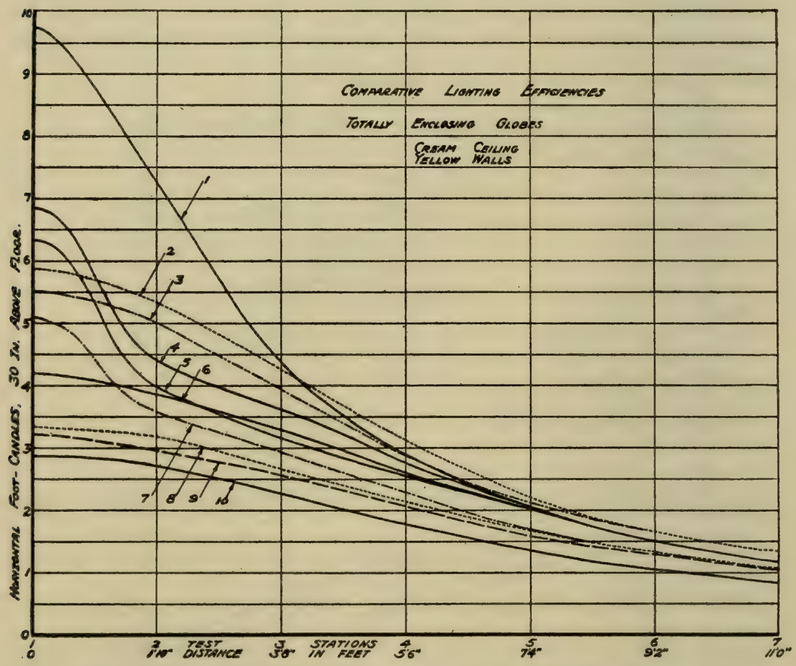

Fig. 3.—Illumination curves showing differences between units of the enclosing globe tppe.

The marked differences in foot-candle efficiencies of the semi-indirect types of units may be appreciated by noting the curves of Fig. 2, and the data of Table III.

With the same candlepower lamp, used with the efficient and the inefficient glassware, there is a range from 3.23 to 2.01 average foot-candles of table-top illumination. Expressed in another way, a certain semi-indirect lighting unit may

be used that will supply 60 per cent. more illumination at the same operating expense than another of the same style. Or if enclosing globes are considered, as in Fig. 3, the maximum range is from 2.81 to 1.60 average foot-candles, where the right gives 75 per cent. more illumination than the wrong globe. Table IV gives further comparative data:

TABLE III.—THE RANGE IN EFFICIENCIES OF INVERTED BOWL UNITS.

Test No.	Lamp	Fixture	Max. Illu.	Min. Illu.	Av. Illu.
1	200 "C"	Dome S-I	10.08	1.38	3.23
2	200 "C"	Dome S-I	7.15	1.33	3.07
3	200 "C"	Bowl S-I	7.11	1.33	—
4	200 "C"	Bowl S-I	6.81	1.33	2.95
5	200 "C"	Dome S-I	6.02	1.51	—
6	200 "C"	Bowl S-I	6.20	1.20	2.76
7	200 "C"	Bowl S-I	5.48	1.22	2.64
8	200 "C"	Bowl S-I	5.23	1.19	2.52
9	150 "B"	Dome S-I	4.20	0.77	1.85
10	200 "C"	Bowl S-I	3.85	1.03	2.14
11	200 "C"	Indirect	3.62	1.05	—
12	200 "C"	Bowl S-I	3.43	1.01	2.01
13	200 "C"	Dome S-I	5.55	1.48	2.92
14	200 "C"	Indirect	3.72	1.07	2.16
15	200 "C"	Bowl S-I	6.18	1.22	2.72
16	200 "C"	Bowl S-I	4.50	1.16	2.40
17	200 "C"	Bowl S-I	6.46	1.25	2.88

TABLE IV.—THE RANGE IN EFFICIENCIES OF ENCLOSING GLOBE UNITS.

Test No.	Lamp	Fixture	Max. Illu.	Min. Illu.	Av. Illu.
1	200 "C"	Cased globe	9.76	1.11	2.81
2	200 "C"	Cased globe	5.87	1.28	—
3	200 "C"	Cased globe	5.50	1.10	—
4	200 "C"	Lt. opal globe	6.84	1.25	2.47
5	200 "C"	Lt. opal globe	6.34	1.17	—
6	200 "C"	Lt. opal globe	4.18	1.27	—
7	200 "C"	Cased globe	5.09	1.07	2.03
8	200 "C"	Lt. opal globe	3.33	1.09	1.95
9	200 "C"	Lt. opal globe	3.20	1.02	1.85
10	200 "C"	Cased globe	2.87	0.81	1.60
11	200 "C"	Cased globe	5.72	1.04	2.03
12	200 "C"	Cased globe	5.74	1.14	2.65
13	200 "C"	Cased globe	5.98	1.31	2.53
14	200 "C"	Lt. opal globe	5.70	1.32	2.54
15	200 "C"	Lt. opal globe	4.31	1.27	2.35

Suppose that the cleaning and the first cost of the different units above mentioned be equal; and this is closely true. Then a difference of 60 per cent. in the illumination means that for equal service, the unit of lower efficiency must be supplied with 60 per cent. more power and 60 per cent. larger lamps. Data from a typical modern office building of 168,000 sq. ft. rentable area, show the annual cost for lighting power to be $8,770.00, and for lamps $1,035.00, or a total of $9,805.00. (See Fig. 4). Surely then, 60 per cent. of this amount, or $5,883.00 is a possible economy not to be neglected.

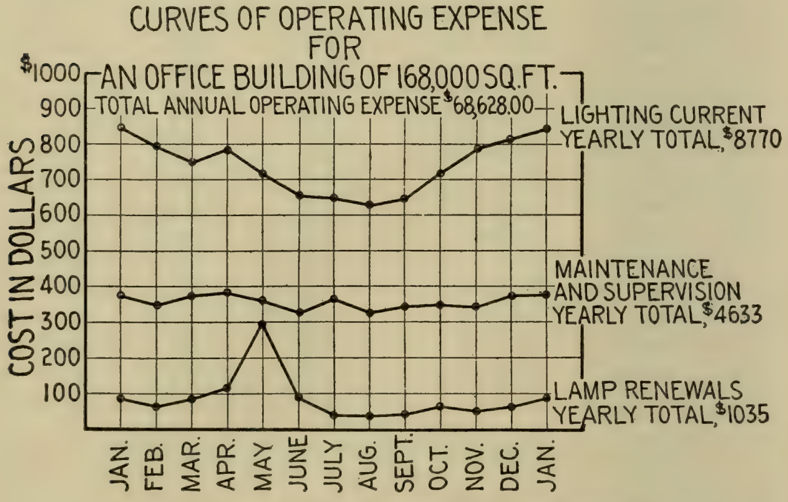

Fig. 4.—Curves of operating expense for an office building.

The question of the proper choice of office lighting fixtures leads to entirely too many ramifications to allow of full consideration in this paper. There may be noted in passing only a few features in addition to illuminating efficiency, that have a bearing upon economical operation. Above all else the glassware must be easy to clean. It must be sturdy and well hung, for the average night janitor has not the delicate fingers of a pianist. The metal of office fixtures should be of bronze or of equally suitable metal and since the units are often adjusted for different lengths in rooms of various heights and to suit peculiar demands of tenants, the use of chain rather than rigid stem fixtures is usually preferable.

Many little "kinks" in fixture construction eventually appear in the operating expense—a matter of whether the lamp may be unscrewed without removing the glass from the supports, or of a small hole drilled in the bottom of a semi-indirect bowl to allow the insertion of a finger so that the janitor may safely support the bowl with one hand.

C. Cleaning Costs.—Cleaning cost is susceptible to marked economies, and is usually the most difficult to concretely study. In order to note the importance of cleaning of lighting glassware, consider Fig. 5 illustrating a not unusual case in which the author, during the investigation of the system of one large office building, removed a semi-indirect bowl, washed it, and immediately repeated an illumination test with results as shown. The average illumination for the entire room was increased 30 per cent.

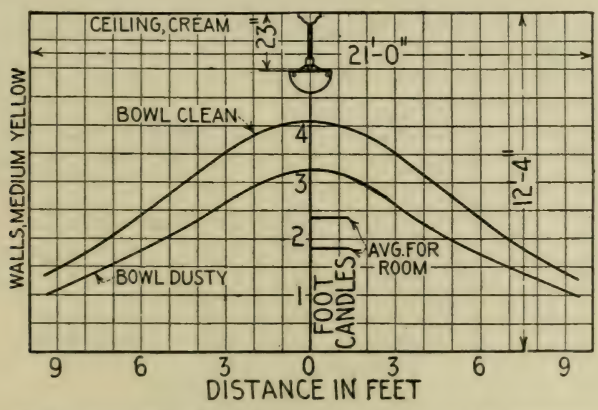

Fig. 5.—Comparison of illumination with clean and dirty glassware.

Among examples of cleaning experience, the author has collected data upon two buildings as follows:

TABLE V.

	Building M	Building O
No. of rooms	250	
No. of fixtures	350	900
Cleaning period	4 weeks	3 weeks
Routine	Scrubbing	Alternate wash and dust
Janitor's salary	$675.00	$720.00
Janitor's supplies	200.00	250.00
Total	875.00	970.00
Per unit per year	2.50	1.07
Per unit per visit	19.2¢	6.2¢

These may probably be taken as two extremes of expense. The average period of cleaning for good service, especially of the semi-indirect glass bowls, is once monthly. This period, of course, will vary with the location. The author in one investigation found that it required 4.5 minutes to remove a semi-indirect glass bowl from a fixture, scrub, dry, and replace it. To shift from one unit to another probably would double this time. These figures are for specific cases only, but they may supply the foundation for a good conception of this feature of lighting economics.

The experience of the author has led him to practically condemn the use of office lighting glassware with sand-roughed surfaces, and to hesitate in recommending the use of acid-roughed (commercially known as satin-finished) glassware.

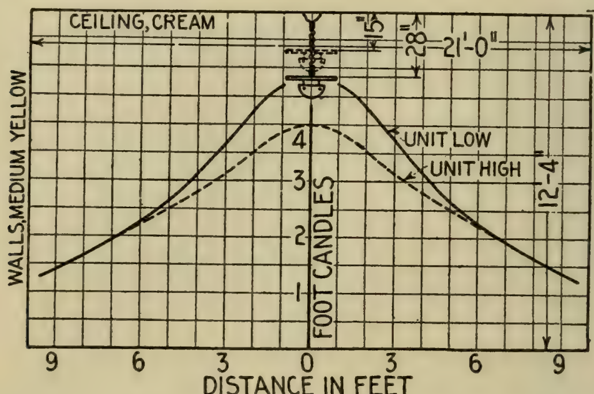

Fig. 6.—Comparison of illumination at different handing-heights of light sources.

D. The Hanging Heights of Light Sources.—Indirectly connected with the economics of office lighting is the question of hanging heights of light sources. It has been the author's experience that most modern lighting units in offices with 11-ft. to 13-ft. ceilings, are hung too low. Except in case of the use of very dense glass semi-indirect bowls, the effect of low-hanging is similar to the results graphically illustrated in Fig. 6. The illumination directly beneath the average semi-indirect bowl or a bowl with upper diffusing dome, is increased by low hanging, but the point to be emphasized is that the room-edge illumination

is not measurably affected. It is this room-edge illumination that is ordinarily most useful, for in nine out of ten cases, the office desks are located against the walls.

It follows that unless photometric measurements are made previous to the purchase of fixtures, money may be uselessly spent for extra lengths of fixtures that serve no useful purpose.

E. The Load Factor.—The lighting load factor of the office building is a comparatively constant one. This has resulted from inadequate provisions for natural daylight, and from the fact that weather or seasonal conditions do not seriously affect the use of artificial illumination. Office tenants often use artificial lighting during all hours of occupancy, daylight or darkness. This brings up a point of contention, namely, whether all tenants should or should not pay each for his own energy consumption. Most office building managers will claim that great savings could be affected if each tenant were individually metered. But, however justified such a charge system would be, it remains a fact that under present conditions the management must provide for and expect wasteful lighting power consumption. This is another argument for the highest utilization efficiency in office lighting systems.

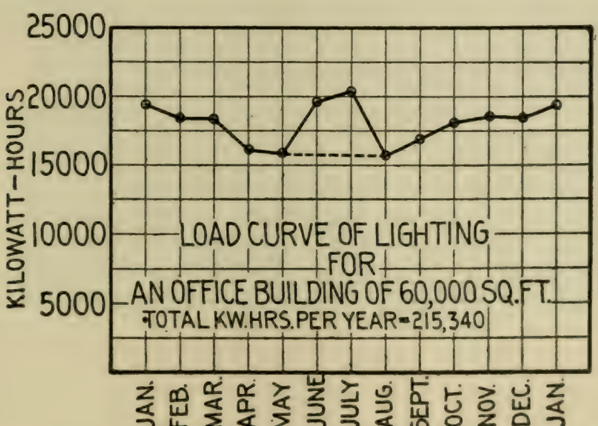

Fig. 7.—Typical load curve of an office building.

A typical load curve of an office building is given in Fig. 7. The dotted line would closely approximate the load of the summer months. The peak of June and July is in this case caused

by extra night janitor service and probably by a superimposed fan load.

F. Economic Lamp Sizes and Proper Voltage.—The most economic voltage at which to operate the lamps ought to be computed for each office building. This factor has usually been overlooked in studies of operating expenses. In the first place the private generating plants often sell excess energy and any means of reducing the building load, or increasing the generator output allows more power to be available for sale. Now the limit of output of a generator is fixed by heating and heating is almost entirely a function of the amperage. If the supply voltage be increased the wattage output is increased without incurring any extra expense for larger generators.

In the second place,—and this is a matter of the greatest importance,—the amount of light is so rapidly increased by relatively slight increases in voltage that even though the lamp life be reduced, it is not always most economical to burn lamps at their rated voltage. If energy costs 10 cents per kw. hr. the characteristic operation of a 60-watt tungsten lamp is as follows:

TABLE VI.

Per cent. Rated voltage	Per cent. Rated wattage	Per cent. Rated cp.	Per cent. Total cost light
96	93.7	86.7	5.1 increased
97	95.3	89.9	3.7 "
98	96.9	93.2	2.3 "
99	98.4	96.5	0.9 "
100	100.0	100.0	0.0
101	101.6	103.5	0.9 decreased
102	103.2	107.2	1.9 "
103	104.8	110.8	2.7 "
104	106.4	114.6	3.3 "

From this table it is evident that for 10-cent energy it would be more economical to boost the lamps above their rated voltage. At some voltage the decreased lamp life and the extra janitor service for making lamp replacements balances the increased amount of light, and this point should be carefully determined for each condition of service and for each cost of energy.

The expense of maintaining a stock of lamps will be reduced if the variety of sizes of lamps be kept small. This is a more important economic consideration than the slightly better effi-

Fig. 8.—Improved lighting of an elevator by means of light interior coloring.

Fig. 9.—Improved lighting of an elevator by means of reflector placed above ceiling hemisphere.

ciency of the large wattage lamps over the smaller. These facts are mentioned in this connection because they are so often neglected in studies of office lighting economics.

G. Facilitating Elevator Service by Improved Illumination.—It has been mentioned before how the height of the modern office building depends upon its elevator service. Nowadays the elevator cars must run on schedule; and on a fast schedule at that. Anything that facilitates loading or unloading will better the service; hence it is within the province of an economic study to consider such means as will allow more passengers to be carried, and these with greater safety.

The writer working along this line studied a number of elevators and found them to be universally darker within the cars than was the case in the adjoining corridor. In entering, some passengers halted on the threshold. Others shuffled their feet and moved towards the rear of the car slowly, as though slightly confused by the difference in lighting intensity. When one considers that the daily transient population of an office building of only moderate size with possibly fifteen elevators will be 20,000 to 25,000 persons, it does not require very much delay upon the part of each traveler to hamper the efficiency of transportation.

We are familiar with the use of small bullseye lights at the edges of the doorways, and these are of some help, no doubt, but the author would hesitate to recommend them in preference to some other methods. One of the simplest, yet always efficacious means, of bettering the car illumination is by using a white interior finish in the upper portion of the car, as shown in Fig. 8. This method, which adds approximately $15.00 annually to the cleaning costs per car, will increase the useful illumination surely 25 per cent., sometimes 40 per cent. Fig. 9 illustrates another car which could not be treated by interior painting but in which excellent illumination was secured by merely backing up the diffusing glass hemisphere set in the ceiling dome with a silvered reflector. These are not new methods, yet careful attention to them means an indisputable saving.

One scheme in connection with elevator operation that is rather unusual, however, has been tried with success. Some of the lost time in elevator operation is occasioned by the inability of the operator to clearly see the edge of the floor and his inability to

bring his car floor to the proper level when stopping. This particularly is the case when rising and moving along the dark face of the elevator shaft. If there is a bright band painted beneath the threshold and on the face of the shaft, say of yellow color, then it is comparatively easy to stop the car just as this band is paralleled by the car floor.

H. The Economy of Light Interior Colorings.—No discussion of the economics of office building lighting would be complete without a brief mention of interior colors and finishes of rooms. Without going into this matter in detail, it is interesting to note the following figures which the author has gathered from the results of a large number of tests.

1. The average increase in desk top illumination caused by cream colored over green walls, with semi-indirect lighting units was found to be 17.4 per cent.
2. The average increase of ivory white over cream colored ceiling, with semi-indirect units was found to be 11.6 per cent.
3. The average increase of cream colored over green walls, with totally enclosing globes was found to be 26.8 per cent.
4. The combined increases caused by ivory white ceiling and cream colored walls, over a cream ceiling and green walls, using semi-indirect bowls was found to be 31.7 per cent.

Referring to Fig. 4, the total annual expense for lighting in a moderate sized structure is about $15,000. If light colored interior painting will increase the illumination 30 per cent., then the monetary equivalent is $5,000 annually. Admittedly the extra cleaning of light colored walls will reduce this saving somewhat, but it has been the writers experience to find that the average office is washed down but once each year, regardless of color. The lighter colored interior will of course increase the daylight illumination and shorten somewhat the hours of artificial lighting.

I. The Relation of Lighting Expense to Total Expense.—In studying the divisions of expense incurred in office building lighting, it is interesting to assemble and compare data as shown in Fig. 10. A comparison of the buildings *A* and *B* will disclose the facts that *B*'s item of excess expense lies in the current con-

sumption, or in the power costs. The reason for this is twofold; there is less daylight in *B;* the fixtures are poorly arranged with less flexibility in switching operations so that several lamps are burned when a tenant really requires but one. These percentages (Fig. 10) are representative of a great many large office buildings.

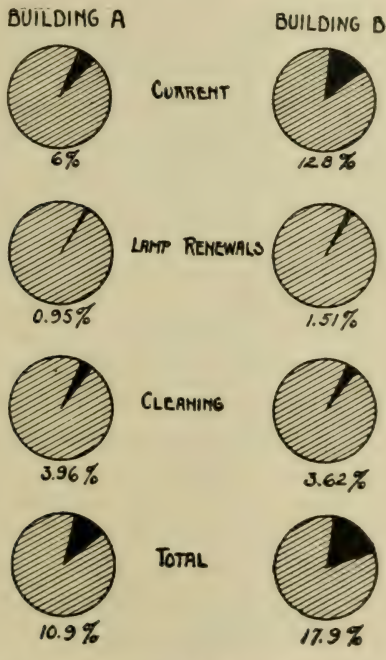

Fig. 10.—Percentages of total operating expense.

A study of the economics of office building lighting is rich in variety, and in the possibilities of profitable return to the manager or owner. In an ultra-modern building every item from proper colored paints to proper voltage of lamps, holds possibilities of waste or of economy. Completed and adequately illuminated, the structure is beautiful by day, almost equally as handsome by night, and certainly a source of great pride and service to owner and tenant.

For their co-operation and interest in the study of this subject, the writer wishes to mention with appreciation the names of

the H. W. Oliver Estate, Mr. Gittens of the Westinghouse Building, and especially Mr. Haywood of the Union Arcade Building, of Pittsburgh.

DISCUSSION.

J. R. Cravath: This paper calls attention to a number of important factors that are frequently overlooked in connection with office building problems. The paper being on economics, the inference may be that the hygienic aspects are not to be considered and I believe they are not touched on directly in the paper. I mean by the hygienic aspect, the results of glare from whatever system of lighting is adopted. However, in the tests which are given, one may infer that some consideration has been given to the hygienic aspects, because semi-indirect bowls and globe units are tested and compared. Now it seems to me, in a problem of this kind, if we are to consider the hygienic aspects at all, we ought to give them full consideration. Now in the case of these bowls which probably show the highest efficiency although no data is given, the chances are they are bowls which also give the most glare, so that the whole story is not told when we consider the efficiency alone. If we are to consider the efficiency alone, why put in a semi-direct system at all? Why not put in a direct system? Another thing is the question of uniformity. One might infer from these tables that the one giving the highest average illumination was the most desirable, but when we look at the curves, we see that the ones giving the highest efficiency are also the ones giving the greatest degree of non-uniformity, so that lighting over in the corners of the room is not nearly as good as with some of the less efficient ones. These are some of the things that must be considered if we are to consider the problem as a whole. If we are simply to consider it from the standpoint of cheapness, it seems to me that we might obtain a still more efficient lay-out than is implied in these tables. If the glare evil is fully considered we might, perhaps, select more dense bowls and a less efficient system and yet be fully justified.

Earl A. Anderson: That the economic advantage of properly maintaining lighting in offices as brought out by Mr. Hibben

is not overdrawn is illustrated by a recent series of tests in a modern Cleveland office building.

The walls and ceiling of the particular area in question were of sand surfaced plaster painted a yellowish cream. This paint had been in service since the erection of the building, more than two years back, and had become considerably blackened. The office was used for bookkeeping and for some time prior to the investigation, the occupants had complained that the light was not sufficient for comfort. As a result, the owners of the building called upon the Engineering Department at Nela Park for advice on re-designing the lighting system. The engineering representative found a well-planned indirect silvered glass layout using practically 2 watts per square foot. Instead of increasing the wattage or changing the system, he recommended that the ceiling be repainted and that the depreciation of the units be checked up. The reflectors had had the benefit of a regular monthly cleaning schedule but the vacuum tungsten lamps had been burning since the building was first occupied.

Results of the tests in typical bays in the room, before and after cleaning the reflectors, after replacing the old lamps with new ones, and after repainting the ceiling and walls, are given in the following summary:

	Foot-candles	Per cent.
Before cleaning reflectors	3.75	100
After cleaning reflectors	4.68	125
Cleaned reflectors—new lamps	5.26	140
Cleaned reflectors—new lamps—repainted ceiling	6.78	181

The total improvement was found to amount to more than three-fourths of the light secured prior to the investigation. Repainting the ceiling with a new paint of good reflecting characteristics, somewhat lighter in tone than that originally used, resulted in an increase of 40 per cent. in useful light. It is interesting to note that the 25 per cent. improvement made by wiping out the reflectors caused those in charge of the building to decide upon a weekly cleaning instead of the monthly plan previously observed. A further result was to make certain the refinishing at stated intervals of all ceilings in rooms with indirect lighting.

It is found in many instances that the user has a tendency to

ascribe the falling off in illumination to lamp depreciation principally, whereas actually, as in this test, even under adverse conditions this item is likely to be small in comparison with the increase in reflector and ceiling losses.

WALTER R. MOULTON: This problem of spacing for short term leases in office buildings recently came up in connection with a large building where certain floors were reserved for small tenants on short term leases.

The typical building bay is about 16½ by 18 ft. The space for offices to be considered will be along the outside of the building. There is a corridor running parallel to the wall of the building just inside of the first row of columns. The natural sub-division of the floor would be that in which the entire bay were closed by carrying a partition between each column and from each column to the outside wall. Under this condition the natural location for the lighting outlet would be in the center of the room. Should a small tenant lease one of these rooms and use it as a single room, we would be supplied with a single large fixture in the center. Many small tenants take a room of this size and sub-divide it into two or three smaller rooms. There are two large windows in each bay and there is a possibility of a tenant's wishing to run a partition in between the windows back about two thirds of the distance across the room and from there carry a cross partition at right angles. This makes two small offices about 8 by 12 ft., with a small entrance. The center outlet, provided for the first condition, is worthless under the second arrangement. On the other hand an arrangement that would take care of the second condition would be undesirable if the entire room were used as a unit. An arrangement was finally adopted providing for one center outlet in the standard size room and also one center outlet in each of the three small rooms, should the tenant wish to sub-divide it. These outlets are all properly connected by conduit but the wiring is run only to the center outlet until such a time as the side outlets are required.

This double provision, necessitating additional cost and wiring, made it necessary to confine space for short term small tenants to three floors of the building. It was feared that there might be a great number of tenants of this character, but fortunately the majority of prospective tenants required larger spaces, so that it

will not be necessary to adopt the sub-division planned to any greater extent than originally provided.

Fig. 6 shows a room 21 ft. wide, with ceiling height of 12 ft., 4 in. A semi-indirect fixture is indicated, hanging 23 in. from the ceiling. If the glassware is of heavy density, there will be a decided spot in the center of the ceiling and the distribution of light on the ceiling will not be all that could be desired. It is often necessary to sacrifice actual lighting efficiency for improvement in ceiling distribution. It would seem better practice to have dropped this fixture further away from the ceiling, making its length probably 30 in.

J. B. Jackson (Contributed later): This paper opens up an

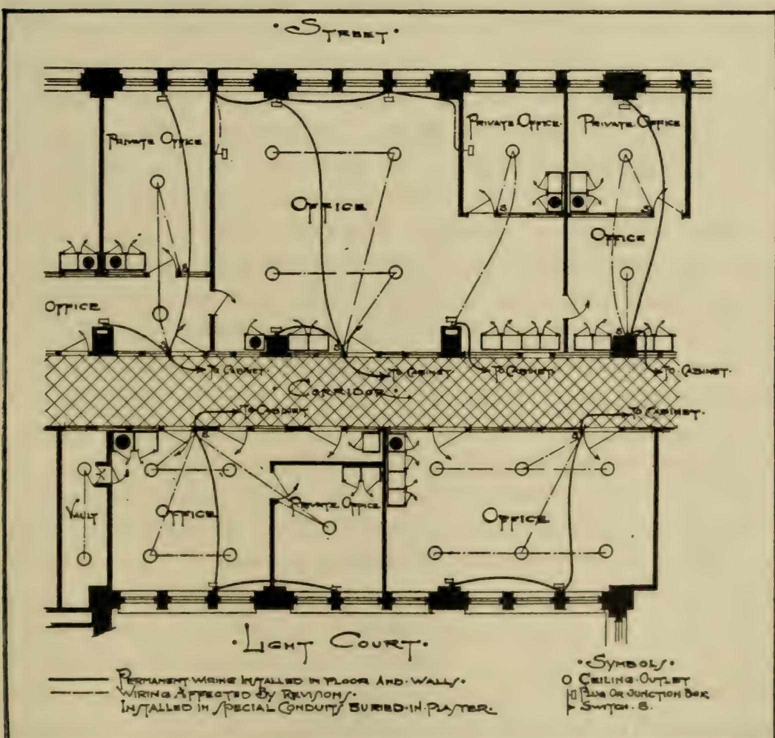

FIG. A.

ertirely new field to the illuminating engineer, and one which is worthy of serious consideration. After all the lighting consumer

is vitally interested in the economical side of the question, the major points of which have been ably covered by Mr. Hibben.

The question of distribution systems is one which has been overlooked in a number of cases. This is one of great importance to the office building manager and owner. Supplementing the paragraph on arrangement of outlets, Fig. A, showing a scheme of wiring made use of in remodeling an existing building might be of value. The figure is self-explanatory and is intended to show the application of a general scheme for locating feeder points in permanent walls. Wiring that is affected by changes in interior walls, special construction is used, which reduces cost of electrical revisions to a minimum.

In Tables III and IV the author presents data on the illumination efficiency of different types of units. It will be noted that the range of maximum to minimum values is high in some cases. I would ask the author if in the selection of a fixture for a given installation, this ratio be a major consideration. What would be the limiting ratios in the type of room he is considering, namely a small room presumably used as a private or semi-private office?

WARD HARRISON: There is one factor which as yet has not been discussed but which I believe comes under both economics of office lighting and hygiene, namely, that in any system of lighting employing central outlets, the illumination near the wall is of a different order of magnitude from that in the center of the room; as shown in Fig. 2 and Fig. 3, this intensity is in no case more than one half and often an even smaller fraction of that prevailing in the central portion.

The growing practice where several people are employed in an office of medium size, is to place the backs of the desks against the wall. In such cases if an attempt is made to provide all the illumination from a central outlet the unit must be of sufficient size to give at least twice the light actually needed in the center of the room to insure a sufficiency on the desks near the wall. If for this arrangement we substitute four to six outlets placed symmetrically about 2½ ft. from the wall, the same intensity on the desks will be secured at a considerable reduction in wattage. Again, even with totally indirect lighting it is safe to say that probably 80 per cent. of the light in the room comes from a spot on the ceiling 6 ft. in diameter above the unit. If one is facing

the wall in such an office, with the usual ceiling height and a width of more than 12 ft., the direction of light will be wrong even though the intensity may be sufficient. From four outlets the proper lighting is secured both from the standpoint of intensity and from the standpoint of direction.

A decided advantage of an arrangement of desks as outlined above, is that if direct lighting units are chosen they are entirely out of the range of vision and their brilliancy is immaterial so far as the glare from the unit itself is concerned or in fact glare from surfaces worked upon because specular reflection from the desk tops is directed away from the eye. We are using a direct system of this kind in many of our own offices and find it entirely satisfactory except for the fact that shadows are somewhat more disturbing than where indirect or dense semi-indirect units are chosen; when reading it leaves nothing to be desired, but when writing a distinct shadow of the hand traveling across the page may become quite troublesome. It is simply for this reason that a change to semi-indirect lighting, using the same outlets, is under consideration.

S. G. HIBBEN: Mr. Cravath is of course entirely correct in his remarks that hygienic aspects of office lighting must be considered as well as some of the other factors,—that is, as well as the factor of actual quantitative illumination. However, I do not want anyone to misinterpret the reasons for the curves as shown in Figs. 2 and 3. They are given primarily to illustrate the fact that there can be a tremendous difference between the quantitative lighting efficiencies of various ordinary commercial office lighting units. I could show, perhaps almost as readily, differences between indirect lighting units of various manufacturers and of various sizes and shapes, but the point to be emphasized is that while the quality of illumination, the hygienic aspect, is important, yet it is in this case not the one of primary importance.

As Mr. Harrison has suggested, in a great many cases the lighting units are so arranged that the question of the intrinsic brilliancy of the source is relatively a minor question because a man working in that room never has occasion to look at the lighting unit itself. I do not mean to say that it is not worth considering, but the question of color of walls is really a more

important factor to the man whose desk faces the wall and whose back is toward the lighting fixture than is the question of the lighting unit itself.

I am interested in Mr. Anderson's remarks because it was found that cleaning was necessary only after they had experienced trouble. That seems to be the keynote of all these maintenance troubles. They will wait until the patient is on the point of death before they administer the medicine. It is false economy to postpone cleaning until the lighting units are so dirty that their appearance is very poor or the lighting is inadequate.

I agree with Mr. Moulton's remarks entirely. It is interesting to note that outlets were provided which were not immediately used; that is, the far-seeing building manager or engineer on the job took occasion to look into the future and provide for possible future space sub-division. The point mentioned by Mr. Harrison along the same line as to whether a single large central outlet be used, or whether four outlets in the corners of the room should be used, is a matter which must be decided by the question of space sub-division, location of furniture, etc., and of course first cost. The first cost of four smaller units is not necessarily very much greater than one single large unit. One of the reasons for this is that the cost of glassware—take the cost of the semi-indirect glass bowl—will not increase in proportion to the diameter of that bowl, but will increase very much faster, so that the four smaller units using smaller lamps and glassware may possibly not cost much more than a single large central one. The questions of wiring and cleaning then become really the deciding factors.

THE INTEGRATING SPHERE AND A NEW TYPE OF COMPENSATING SCREEN.*

BY FRANK A. BENFORD, JR.

Synopsis: The theory of the integrating sphere, as usually given, assumes a certain uniformity of flux distribution that seldom exists in practice. A short discussion of the theory is followed by a review of some of the larger factors that interfere with the application of the mathematics of the subject. From a study of these factors the author was led to adopt a new type of screen, doing away with the present individual screens for comparison and test lamps, and thus eliminating some of the principal sources of error.

A review of the more prominent papers and articles on Ulbricht's integrating sphere, since its introduction sixteen years ago, brings out strongly the fact that the size and direction of experimental errors have been the chief points of interest. This is natural in any radically new piece of apparatus, but even at this date, it will be found that the literature on the subject is largely occupied with determining by test methods the size of these errors, rather than attempting to explain or eliminate them. The reason for this is fairly obvious. The theory of the ideal sphere is remarkably simple; while that of the actual sphere is rather complex. It is true that the theory has been attacked with success by several investigators, but there is one fact that puts a discouraging limit to progress along this road. The action of the sphere depends in a large degree upon the photometric distribution of the unit under test, and photometric distributions do not as a rule lend themselves readily to mathematical treatment.

The ideal sphere has a perfectly diffusing inner surface of a high reflecting power which we will indicate by *k*. A source of light having a spherical intensity of I candles will illuminate the sphere to an intensity

(1) $$E = \frac{I}{R^2} \, \frac{1}{1-k} \text{ foot-candles}$$

* A paper presented at the tenth annual convention of the Illuminating Engineering Society, Philadelphia, Pa., Sept. 18-20, 1916.

where R, the radius of the sphere, is measured in feet.

The brightness of the sphere wall will be

$$(2) \qquad B = \frac{I}{R^2} \quad \frac{k}{1-k} \text{ lumens per square foot.}$$

The opening or window, through which the interior of the sphere is observed, is shielded from the direct rays of the lamp being tested, and the illumination on the window is equal to the average brightness of the interior of the sphere

$$(3) \qquad E_w = \frac{I}{R^2} \quad \frac{k}{1-k} \text{ foot-candles}$$

The above expressions for illumination and brightness are only approximate because several important factors have not been included.

The test unit itself absorbs a certain amount of the light reflected from the sphere walls. Let s represent the area of the unit and let its coefficient of reflection be k_1, the illumination of the unit will in general be equal to the average brightness of the surrounding sphere walls, which of course is lowered by the presence of a light absorbing body.

The amount of light, F_u, absorbed by the unit will be its area times the illumination times the coefficient of absorption

$$(4) \qquad F_u = sB\,(1 - k_1) \text{ lumens.}$$

The loss of light, F_s, on the sphere walls is likewise

$$(5) \qquad F_s = 4\pi R^2 E\,(1 - k) \text{ lumens.}$$

The sum of these two losses must equal the total flux of the light source, and the presence of light absorbing area leads to a wall illumination that is lowered in the ratio

$$(6) \qquad \frac{F_s}{F_u + F_s} = \frac{4\pi R^2 \frac{I}{R^2} \quad \frac{1}{1-k}(1-k)}{s\frac{I}{R^2} \quad \frac{k}{1-k}(1-k_1) + 4\pi R^2 \frac{I}{R^2} \quad \frac{1}{1-k}(1-k)}$$

$$= \frac{4\pi I}{s\frac{I}{R^2} \quad \frac{k}{1-k}(1-k_1) + 4\pi I} \text{ numeric}$$

$$(7) \qquad \text{or } \frac{E}{E_o} = \frac{1}{\frac{sk(1-k_1)}{4\pi R^2(1-k)} + 1} \text{ numeric}$$

where E is the illumination with, and E_0 is the illumination without the foreign body.

This factor for the absorption of light by a foreign body can only be true when the body is shielded from the direct light of the source, and when the body is located so that it receives an illumination that is equal to the average brightness of the sphere. When it is remembered that most lighting units have a strong directional characteristic it is apparent that the illumination over the surface of the sphere may vary considerably and the illumination of any foreign body in the sphere will vary as the body approaches or recedes from the brighter sections, and the above equations lose much in practical value.

The test unit is usually placed in a fixed position and the distribution of brightness on the sphere walls depends upon the photometric distribution of the unit. This is illustrated somewhat inexactly by the illumination shown in Fig. 2. The comparison lamp is often placed midway between the center and the bottom of the sphere and consequently the bottom of the sphere will be most highly illuminated by this lamp. The absorption of light by the test unit will in general be less for light from the comparison lamp than for light from its own lamp and as a result the true absorption cannot be determined by test methods.

It is common practice to use three screens in the sphere. The smallest is placed in a horizontal plane between the comparison and test lamps so that the direct light f1om the former cannot reach the latter. A screen of somewhat larger size is placed between the comparison lamp and the reading window so that the window receives only reflected light. The largest screen shields the window from the direct light of the test unit. As in the case of the test unit itself the amount of reflected light that is absorbed by these screens depends upon the relative position of the screens and the dark and light portions of the sphere. Here again obviously the photometric distribution has an effect that is indeterminate, at least by test methods.

Another and greater variation in the performance of the sphere is caused by the variable amount of direct light that may fall upon the three screens. The screen in front of the test lamp is only half as far away as the section of sphere it shadows and the

direct illumination is four times as great. As this illumination may vary from zero to the maximum possible from the test unit, it is evident that here is a prolific source of error.

The screens have a secondary effect upon the amount of light absorbed by the test unit. The usual effect is to increase the amount of light absorbed when the screen receives a higher initial illumination than the other portions of the sphere.

This interrelation between phenomena is one of the features that make the theory and practical use of the sphere so difficult. Each phenomena is linked with all the others, and while the errors introduced by the neglect or lack of control of any one may seem insignificant, the sum of such errors makes the difference between good and indifferent photometry.

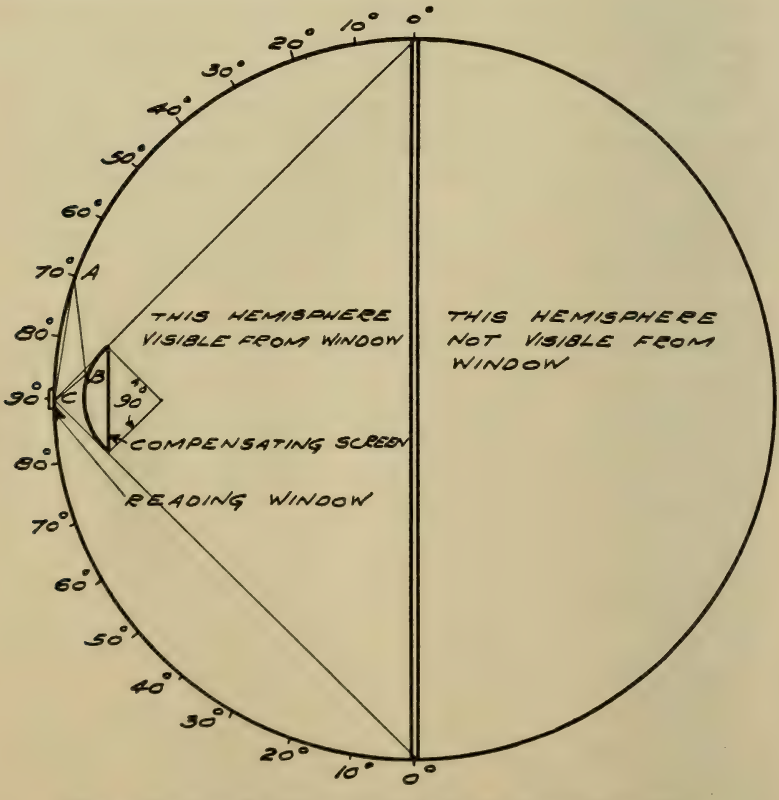

Fig. 1.—Diagram of location and optical action of compensating screen.

It has long been known that ground glass or porcelain, such as is used for the sphere window does not transmit equally, light coming from different directions. This phenomena in conjunction with the variations of brightness within the sphere leads to results not in accordance with theory. The transmission characteristics of the glass used in this experimental work was as follows: the angles being measured as indicated in Fig. 1, the 45° direction being given a value of 100.

Angle on sphere	0	10	20	30	40	50	60	70	80	90
Transmission ..	111	110	107	104	101	98	94	89	82	73

Several years' experience with a one-meter sphere has brought to the author's attention the various peculiarities outlined above and quite naturally some attempt has been made to study and minimize them. Fortunately, a two-meter sphere is available for carrying on much of the regular work of the laboratory, leaving the smaller and more erratic one free for experimental work.

The screens are probably the first to suggest themselves as points of possible attack. Ulbricht has arrived at the conclusion that the "error due to a screen is a minimum when the distance of the screen from the lamp is 0.4 of the distance of the latter from the measuring apparatus." Ulbricht determined this ratio by finding the position that would make a minimum of the combined area of the shadow of the screen and the area on the opposite wall concealed by th escreen. This neglects entirely the possible effects due to light absorbed by the screen and the secondary change in the flux absorbed by the light source itself. These two variables become smaller as the screen recedes from the lighting unit and reach zero value when the screen reaches the sphere wall. As it is approaching the reading window, it must stop some distance away in order to allow light from the sphere walls to reach the window. The minimum distance between the window and screen is determined by another consideration.

Assume for the sake of illustration that the light scource is at the center of the sphere and that the screen is at 0.4 of the radius from the center. The amount of sphere wall concealed and shadowed is a minimum. If the screen is brought closer to the window and at the same time kept as small as is consistent with concealing the light source, the shadow around the window will

grow less, but the section of sphere concealed will increase rapidly. Placing the screen so that it conceals a large section, say, one-quarter of the sphere area, the following conditions obtain:

Absorption of light by light source is near a minimum.
Absorption of light by screen is near a minimum.
Shadow of screen is near a minimum.
Concealed sphere area is large.

Three equal units having (*a*) strong downward, (*b*) uniform and (*c*) strong horizontal characteristics will give a descending series of apparent photometric values on account of the increasing amount of light on the concealed section of the sphere. It is evident that this position for the screen will not do. Bringing the screen closer until it conceals exactly half of the sphere, the three equal units, (*a*), (*b*) and (*c*) will give equal illumination at the window because all zones around the lamp are treated equally, exactly half of each zone reflecting light to the reading window. The readings in each case will be smaller than when practically all the sphere is exposed, but the three types of distribution will give equal readings and thus the light distribution will cease to have an effect upon the photometric results.

The presence of the screen so close to the reading window will evidently have a disturbing action and this, in connection with the transmission data just given, makes some kind of correction necessary so that the photometer at the window will give equal readings for equal amounts of light reflected from any part of the hemisphere. This desirable condition was arrived at by a preliminary calculation of the form of the compensating screen illustrated by Fig. 3, followed by tests that pointed out the needed alterations.

The compensating feature of the screen is obtained by placing a convex spherical mirror of 90° total arc on the window side of the single screen placed directly in front of the window as shown by Fig. 1. An observer at the reading window sees the image of the entire visible hemisphere in the mirror. There are thus two paths over which light from any section of the hemisphere may reach the window. The light that takes the direct path does not have equal effects, the sections nearer the window being less

Fig. 2.—Assembled views showing location of screen and illustrating effect of photometric distribution of test unit.

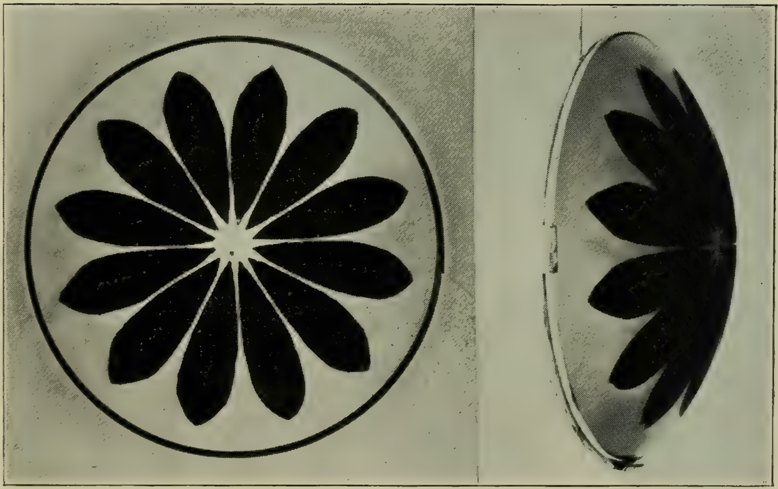

Fig. 3.—Front and side views of compensating screen.

effective for getting light to the photometer. The light coming over the second path *via* the mirror is used to compensate for these variations. In the sketch a ray, *AC*, goes directly from the 70° point to the window and according to the window transmission data, the transmission is 89 as compared with 111 for light from the 0° point on the sphere. There is thus the difference between 89 and 111 to be made up by the mirror and this is readily accomplished by opaquing sections of the mirror and leaving clear an area just sufficient to increase the total transmission from 89 to 111. The path of this compensating ray is *ABC* in the figure.

The final form of the compensating screen is shown in Figs. 2 and 3. Fig. 2 also shows the relative size and position when assembled in the sphere. The small screen between lamps is used as before.

The form of the opaque petals on the mirror was calculated from the known characteristics of the window and the petals were then painted with a pigment that could be easily removed. This was necessary because there was no allowance made in the calculations for the interference of the screen itself.

These final corrections were made as follows: Half of the sphere was removed and the opening was covered with a black screen having an opening that permitted a beam of light to enter the hemisphere. A small incandescent projector was mounted on a turntable and the projector had also a vertical adjustment so that a spot of light could be thrown on any portion of the hemisphere. This beam passed through the geometric center of the sphere and its direction of incidence was always normal.

The coefficient of reflection of the sphere paint is 0.83. The integrating factor is, therefore, $\frac{1}{1-0.83} = 6$ for the complete sphere. Half of the sphere being under observation the proportion of total light to direct light (after one reflection) is 3 to 1. This would reduce the accuracy of observation of any change in the same ratio. The integrating factor of the hemisphere is

$$1 + \tfrac{1}{2}k + \tfrac{1}{4}k^2 + \tfrac{1}{8}k^3 + \ldots \text{etc.} = \frac{1.}{1-\frac{k}{2}} = 1.7$$

and the washing out effect of the integrated light is about half what it was for the complete sphere.

More important however than the decrease in the amount of uniformly reflected light is the removal of the light source from the interior of the hemisphere, thus eliminating any possibility of the absorption of light by the projector casing affecting the results.

The spot of light covered an arc of 12° on the sphere wall. The first run was made without the mirror to find the effect of a simple screen so close to the window. The results of this test were as follows, the 30° position on the sphere being given an arbitrary value of 100:

PLANE SCREEN.

Angle on sphere	0	10	20	30	40	50	60	70	80	90
Photometer reading.....	-	99	100	100	99	99	123	238	333	—

These results show the effect of the pocketing of the light between the screen and the window when the spot of light approached the latter, and it seems highly improbable that a simple screen could be used with any success in this location.

The compensating mirror with the opaque petals in their original calculated form, gave readings as follows:

CALCULATING FORM OF COMPENSATING SCREEN.

Angle on sphere	0	10	20	30	40	50	60	70	80	90
Photometric reading....	-	96	98	100	101	106	109	104	98	—

These readings at once indicated the changes required.

After several small alterations in the form of the petals, the photometric readings between 80° and 10° were brought to the following values:

FINAL FORM OF COMPENSATING SCREEN.

Angle on sphere	0	10	20	30	40	50	60	70	80	90
Photometric reading....	-	98	100	100	101	100	100	99	98	—

It is believed that the results obtained with this sphere are, but for one exception, almost totally independent of the photometric characteristic of the units tested. The exception is, of course, the variation in the amount of light absorbed by the test unit. In order to find out what the residual errors are, five units of different sizes and distributions were tested, first on a distribution photometer, second, in the one-meter sphere with the

usual equipments of screens, and third, in the same sphere with the compensating screen. The results of this test are shown in the following tabulation:

RESIDUAL ERRORS.
(One-meter sphere.)

Unit	Lamp	Distribution photometer	Three screens	Compensating screen
Holophane .. E 40	40-W. Mazda B	1.000	0.962	0.999
Holophane .. F 40	40-W. Mazda B	1.000	0.980	1.001
Holophane .. XI 100	100-W. Mazda C	1.000	0.962	1.002
Holophane .. XI 200 VF	200-W. Mazda C	1.000	1.013	0.989
Holophane .. XE 200 VF	200-W. Mazda C	1.000	1.024	1.008

A comparison of the two sets of results shows a very substantial increase in accuracy, the results so far being comparable with those obtained with a sphere of double the diameter. It is highly probable that further experience with the compensating screen will lead to changes in the test method to overcome the errors still remaining. Before the screen was tested it was suspected that the presence of the light absorbing black petals on the mirror would lead to serious unbalancing effects but apparently this fear was not justified.

DISCUSSION.

C. H. SHARP: The device which Mr. Benford has created for eliminating the outstanding errors of the sphere is a very ingenious one and shows careful thought and study of the problem. A word of caution should be spoken. The values given in the table on page 1001 of transmission of a diffusing glass window, showing errors ranging from +11 per cent. to —27 per cent., may make it appear that the sphere is subject to some very large errors. I am sorry that Mr. Benford has not made an express statement of the fact that those errors are reflected in only a minor degree in the results obtained in testing with the sphere. There are other conditions which tend to wash out such errors. For instance, if the sphere is of sufficient size, all of these corrections of which Mr. Benford speaks practically go by the board. Unless you are trying to work with too small a sphere, you are all right anyway. Next, if you are working with light sources which are similar, and using the substitution method, most of

these errors are eliminated. Mr. Benford has some very sensible remarks about the fact that you can make a nice theory of the screen errors and foreign body errors in the sphere, basing it on a uniform distribution of light about the source of light. If you had a source of light of that kind, you wouldn't need the sphere anyway; and if you base your theory on that assumption and then use your sphere with sources of light of entirely different distributions your theory will not apply. You have simply got to play safe by using a big enough sphere and using it in a proper way.

The theory of the sphere was very completely treated by Ulbricht, but Mr. Benford's statement of the conditions governing the best position of the screen does not seem to be just what Ulbricht gave. Ulbricht showed that the light which must be reflected at least twice before it can reach the window must be a minimum. Hence the flux falling directly on the screen plus the flux falling directly on the portion of the sphere which the screen shades off from the window must have a minimum value.

Now we must remember that even with different distributions of the sources of light, the reflections inside the sphere tend to make uniform to a very considerable degree the brightness of the interior of the sphere, and so the errors are very greatly reduced. Furthermore it should be noted that a plane white screen such as is ordinarily used, acts to a certain extent as a compensating screen, as does this screen of Mr. Benford's; that is to say, the side of the screen which is turned toward the window reflects a certain amount of light directly on to the window which serves as a partial compensation for the losses. The compensation which Mr. Benford gets can undoubtedly be made very complete unless the lamp being measured throws more light on the shaded than the unshaded hemisphere, or *vice versa.* However, the sphere without the compensating screen, when it is big enough, when the screens are not too big and the proper precautions are used to avoid error, is a good instrument and capable of measuring so nearly within the limits of actual observational errors that, for the great majority of work, it is hardly necessary to introduce any complication. Mr. Benford has shown us how a smaller sphere may be equipped so as to approach the large

sphere in accuracy, and in so doing has made a very valuable contribution to the photometric art.

I want to call attention to the fact that in measuring a source of light like an incandescent lamp, where the base necessarily cuts off a certain amount of light in one direction, the most advantageous position is with the base toward the screen and toward the window, because then there is a minimum loss due to the screening-off effect. This, in the case of modern lamps, would require the window to be at the top of the sphere, because the lamp must be in a vertical position. Of course that is an inconvenient place for the window, and I presume that is why it has not been adopted in the past.

F. C. CALDWELL: I want to emphasize one important point about this work, and that is that it does make the smaller sizes of sphere more practicable. Dr. Sharp has very properly said that if you make the sphere large enough, you don't need this, but the two meter sphere is at once a very expensive proposition and a thing which takes a good deal of space. The beauty of this work is that it makes possible the more general use of the sphere by increasing accuracy of the smaller sizes.

PRESTON S. MILLAR: As one of those who was rather active in the promotion of the use of the integrating sphere in the very earliest stages of its use in this country, I am most interested to see work being continued on the refinement of the apparatus which makes it more nearly perfect for our general use. It is important to bear in mind that this work which is being done is in refinement in the sphere. The first sphere I ever used was 12 in. in diameter. Since that time use of the sphere has grown until now we know 100-in. spheres in this country and 40-in. spheres are being found to be quite practicable, with reasonably good screen equipment, for tests of any size of incandescent lamp with which we have to do to-day. It is interesting to note that to-day the integrating sphere is the only integrating apparatus which is being used largely in practical photometric work. It is being used for gas and the electric arc, as well as incandescent lamps, and is giving satisfactory results as an approved appliance to-day. The work now being done in the development of the sphere is more largely along the line of adapting it for rapid, practical commercial work than for adapting it to more

accurate precision laboratory work, though efforts along both lines are of course in order.

FRANCIS E. CADY: This work on the integrating sphere is very interesting to us at the Nela Laboratory, because it indicates a decided advance and a definite line of attack on the problem of the mean spherical candlepower which we have been interested in now for the past 12 years. The point raised regarding the size of the sphere was that which struck me in reading the paper, and it is quite true that it is important as aiding in the use of the small sphere and also that it is not so important in the larger sphere. One point which interested me considerably was the accuracy shown of the results of the tests. These values are given out to tenths of a per cent. I remember very well some years ago when an accuracy of 2 per cent. was considered very high for even standard work. When working under conditions where everything was as good as possible, we began to be able to get better results than a per cent., but in the measurement of units where a reflector is involved, it seems to me that to speak of an accuracy of tenths of a per cent. is pushing photometric work pretty far. The results shown would indicate that, as far as the instrument is concerned, it is almost perfect, because the largest error indicated in the last column is less than 2 per cent., and I would like to ask Mr. Benford whether he was able to duplicate those results?

F. A. BENFORD: Dr. Sharp has taken notice of the table on page 1001, where the transmissions of the window are given. That is liable to be misunderstood, but as Dr. Sharp says, the multiple reflections within the sphere tend to eliminate these differences. The reflected light is ordinarily five times as great in amount as the direct light, and these factors have no effect on the light after one reflection; the net effect is small, especially in a large sphere.

In determining the location of the screen so that it would have minimum effect, Ulbricht made a number of assumptions in order to simplify the problem. First among these was the assumption of a perfectly uniform distribution of light from the test lamp. He then wrote equations for the amounts of light on the *first reflection* that was concealed from the reading window.

This light was on the side of the screen next to the lamp and on the portion of the sphere wall concealed by the screen. The quantity of light missing from the shadowed area around the reading window is identical with the first reflection of light from the screen. The back of the shield is as bright as the directly illuminated sections of the sphere, minus again the brightness due to the first reflection. Making a minimum of the first reflection from the screen and concealed area is then the same as making a minimum of the shadow and the concealed area. In view of the apparent exactness of the solution, *i. e.*, 0.39 of the radius, it is interesting to note that Ulbricht made quite a number of simplifying assumptions in both the physical conception of the various areas and also in the mathematics during the process of solution. The solution 0.39 radius really applies only to a perfectly symmetrical source at the *center* of the sphere and in addition it is assumed the same size of screen would be used at all positions, and also that the total absorption of light has no influence on the problem. In practice the test lamp is nearly always well above the center of the sphere and the photometric intensities toward the concealed area and toward the screen are widely different. This solution of the screen position problem must be regarded as a practical solution by a skilled photometrician rather than a solution having general validity.

N. K. CHANEY (Contributed later): Mr. Benford's modified screen arrangement involves a very interesting and novel departure from the principles which govern the proper arrangement of the screen in the standard sphere.

But the limitations of this departure and its co-relation with the general theory of screen practice is not clearly brought out. There are certain simple mathematical generalizations governing the behavior of the screen in the sphere which are of perfectly general validity and universally applicable,[1] yet the author states that "photometric distributions do not as a rule lend themselves readily to mathematical treatment." He introduces some confusion into a sufficiently complex subject by overlooking the fact that he is dealing with abnormal conditions involving special sources of error which have little significance or existence in

[1] Trans. I. E. S., Vol. X, p. I.

spheres properly proportioned in size to the character of the light sources.

Light sources with glass reflectors such as the author employed, require larger screens than are mathematically permissible in a 1-meter sphere. Hence with the standard screen arrangement Mr. Benford would of course be compelled to use a screen too large for his sphere, and place it so close to his light source that secondary errors might arise from trapped light, and irregular absorption of reflected light upon which he lays so much stress, and which would be wholly absent in a slightly larger sphere.

The essence of the paper is a clever adaptation of a *small* sphere to a class of work for which it is not normally designed. But this adaptation in no sense constitutes a fundamentally improved type of integrating apparatus. It is simply an ingenious makeshift to avoid the larger sphere and it suffers corresponding limitations.

In it a light source with a side reflector will give much higher values (15 to 20 per cent.) when the light is directed toward the screen than when it is directed to back of the sphere. A properly designed standard sphere would show no difference. In other words, Mr. Benford's arrangement is primarily limited to radically symmetrical light sources such as he used, and cannot be used for other asymmetrical sources *unless they can be so directed as to always insure exactly one half of the total light flux falling on the rear hemisphere.* This last requirement is essential to his method or large screen errors are possible.

Thus the paper suggests no change whatever in the screen arrangement of the larger spheres for which Ulbricht's original formula is absolutely correct.

In regard to the modified screen itself, certain features such as the 90-deg. arc mirror are probably superfluous. The essential features are (1) the position, so that exactly one half of the sphere wall is screened from the test plate and (2) the blackening of the side of the screen next the test plate to cut down the error due to trapped light which rises from the close proximity of the screen to the sphere wall.

According to the author there are two sources of error with

his arrangement arising from the abnormal behavior of light falling near the test plate (*e. g.*, the 80-deg. position, Fig. 1).

(*a*) A loss of 18 per cent. in test plate illumination through low transmission factor for this position.

(*b*) A gain of 133 per cent. by reason of trapped light between screen and test plate.

The net result is that direct light falling on this area gives double the true illumination value at the test plate. Hence compensation by a 90-deg. arc mirror for the low transmission factor at this region would seem to be carrying coals to Newcastle. In fact a transmission factor five times lower would be very useful. A plain black circle of calibrated width, painted on the back of a plain flat screen to cut down the excess of trapped light seems sufficiently complicated for all practical purposes.

It should be noted that both of these sources of error disappear in the larger sphere since the screen is too far away to trap the light appreciably, and further, the area near the test plate where the principal observations occur is shadowed from direct light by the screen.

Thus the low transmission value of this area is taken care of by the sphere constant as obtained with the standard lamp.

F. A. BENFORD, JR.: Dr. Chaney lays stress upon what he takes to be the fundamental principles of the integrating sphere and he considers the author's deviation from the usual screen arrangement a violation of these principles.

In his original treatment of this subject, Ulbricht was under no misconception as to the basic nature of the screen theory. At best it is only an approximation, and Ulbricht was careful to point out this fact. His handling of the subject is a series of approximations and short-cuts that lead to a rather crude result. The best proof of this is found in every day practice. Screen corrections may be calculated, or determined by test, only under the most favorable conditions, that is when the effect of the screen is very small. This is hardly the characteristic of a well-rounded theory but it is a certain indication of incompleteness or too many assumptions in its development.

The screen equations bear on their faces no suggestion of a

limiting size of screen, beyond which they do not apply. There is nothing mathematically impossible in the use of a 10-in. screen or a 20-in. screen, in a 40-in. sphere, but experience teaches us that the mathematics of the screen theory fail under these circumstances. Under less severe conditions, the failure of the screen theory is less complete and we use it as a matter of expediency. Ulbricht clearly recognized the semi-empirical nature of the screen equations when he determined the greatest permissible size of screen. With these things in mind, it is difficult to be reconciled to the statement that "there are certain simple mathematical generalizations governing the behavior of the screen in the sphere which are of perfectly general validity and universally applicable.

In justification of the remark that "photometric distributions do not as a rule lend themselves readily to mathematical treatment," I would refer Dr. Chaney to his own excellent paper in Vol. X of the TRANSACTIONS, where he states that "as Ulbricht has shown, if the light sources have a pronounced asymmetry the relative flux in the different directions must be determined from the distribution curves of the lamps and corrected for. This is obviously unsatisfactory, . . ." The dissatisfaction arises from the work involved and the uncertainty of the results. This is an important point, as all commercial sources are "asymmetrical" with reference to the screens. Accurate point-by-point photometry of units such as refractors or side lighting reflectors involves a large amount of work, and it is with these distributions that the usual sphere arrangement is most liable to err beyond allowable limits and thus deprive us of a simple means of checking the point-by-point data.

The objection raised that great care must be taken to insure exactly half of the flux falling on the rear hemisphere is not borne out in practice, for it is an easy matter to turn the unit through exactly 180 deg. and take an average of the two positions. This has been tried and below is given the results of tests on two extremely asymmetrical side lighting units. The readings with the unit pointed in opposite directions from a vertical axis are averaged and divided by the average of the whole test on each unit in order that the variations may be more apparent.

ORIENTATION OF UNIT.

Reflector lamp		0°+180°	45°+225°	90°+270°	135°+315°
Bal 100	100-watt MAZDA B	0.997	0.998	1.004	1.001
Holophane 983	100 " " "	1.003	0.995	0.999	1.003

It is evident, so far as these simple tests show, that the compensating screen is capable of giving accurate results for asymmetrical distributions. In this connection it is interesting to note the results obtained by the Bureau of Standards with a sphere of exceptional qualifications[1] and the standard screen arrangement. The test was a severe one on account of the small size of the spot illuminated by direct light, yet it shows that a properly designed sphere still contains rather large possibilities in the way of unexplained variations. Following the previous method of tabulation, the Bureau of Standards' results are:

ORIENTATION OF UNIT.

Reflector lamp	0°+180°	45°+225°	90°+270°	135°+315°
Parabolic lamp	0.994	1.000	1.012	0.994

The reference to "two sources of error with his arrangement" can only be accounted for, perhaps, as being the result of a hasty reading of the paper, for the figures quoted refer, not to the compensating screen, but to a plain screen. This screen was tested in order to prepare for a possible objection to the complicated nature of the spherical mirror.

[1] Trans. I. E. S., vol. XI p. 453.

LIGHTING OF THE CLEVELAND MUSEUM OF ART.*

REPORT OF THE COMMITTEE ON LIGHTING, SUBMITTED BY E. P. HYDE, CHAIRMAN.

In this paper has been included the report of a committee selected by the Board of Trustees of the Cleveland Museum of Art, to make recommendations to the Museum Building Committee concerning the best methods and means of lighting the Museum. The report referred to was as follows:

Gentlemen: Your Committee on Lighting desires to submit the following report of its activities in connection with the design and supervision of the installations provided for the control of daylight and for the supply and control of artificial light in the rotunda, garden court and various exhibition rooms of the museum. At the outset the committee wishes to express its obligations to Messrs. E. J. Edwards, Ward Harrison and M. Luckiesh, who, acting as a sub-committee, assumed the burden of the work in proposing and supervising the various installations under the general direction of the larger committee.

Your Committee on Lighting deems it important also to record at the outset that the committee was not appointed until after the museum building had been completely designed and constructed in its essential parts, so that the lighting installations necessarily had to be designed in a manner consistent with the design of the building. The committee wishes to take advantage of this opportunity, for the information of others who may contemplate the construction of similar buildings, to urge the advisability of securing advice in regard to lighting before the design of the building has been decided upon, in order to anticipate the requirements in this regard. This is extremely important in consideration of proper daylight provision, and is to be recommended also in the interest of securing the best possible installation for artificial lighting.

In the design of the artificial lighting installations of the top-lighted paintings galleries two somewhat opposing elements enter.

* A paper presented at the tenth annual convention of the Illuminating Engineering Society, Philadelphia, Pa., Sept. 18-20, 1916.

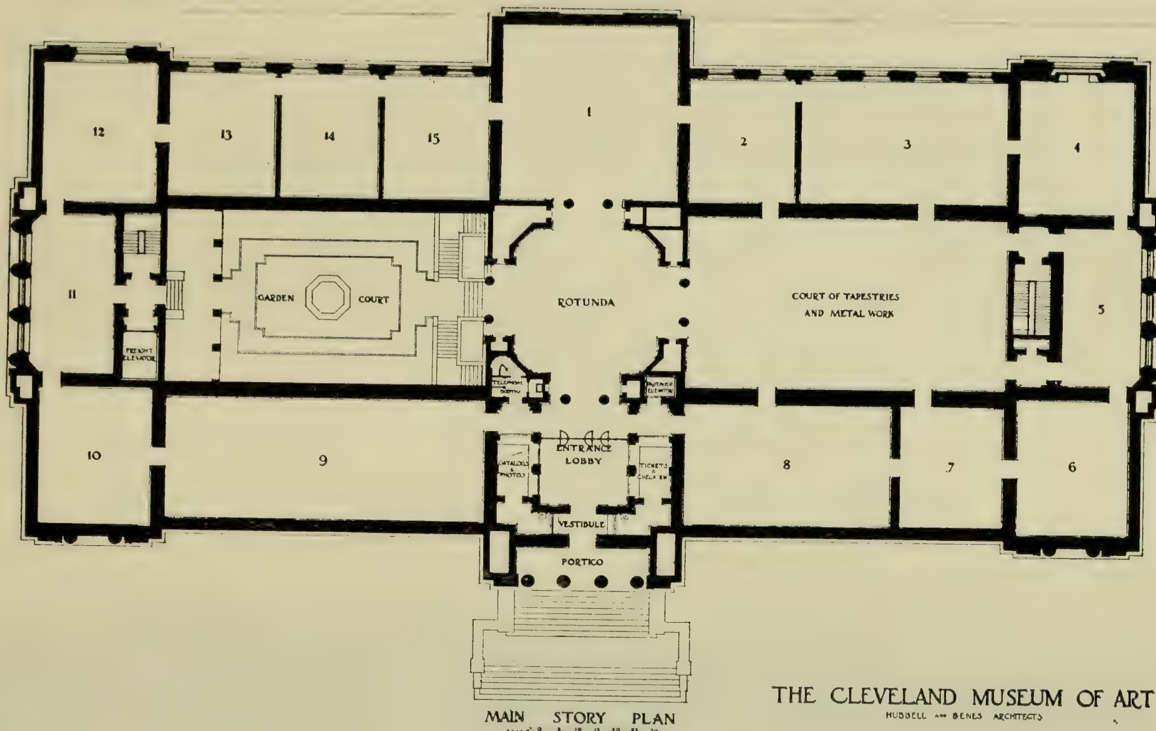

Fig. 1.—General floor plan.

It was not found feasible to produce the most desirable illumination of the hanging walls and at the same time to secure the most pleasing effect on the ceilings from the standpoint of the uniform brightness of the sub-skylight. It was the judgment of the committee that any necessary sacrifice in the latter should be made in order to accomplish the best possible lighting of the hanging walls of the galleries. After this had been done every effort was made to render the sub-skylights as uniform in brightness and otherwise as pleasing as it was possible to do.

In the detailed reports of the installations in the various rooms the peculiar requirements and the methods employed to meet these requirements will be fully discussed. We wish to note, however, in this introduction, two features of a more or less general character, which are unique and hence worthy of special mention. The control of daylight in the top-lighted paintings galleries has been accomplished by the special design of a comprehensive system of adjustible metal louvers. This system was the ultimate development of efforts to accomplish, without the use of random perishable cloth screens, the first three of the following four desiderata, which the committee formulated as criteria to be met by both the daylight and artificial light installations: (1) that the brightness of the floor and ceiling should not be disproportionately large in comparison with the brightness of the walls; (2) that the component of light vertically downward should not be disproportionately large in comparison with that directed toward the important hanging space on the walls; (3) that there should be no opportunity for the reflection of brightly illuminated portions of the skylight, or of any other bright part of the room, from the glazed pictures into the eye of an observer standing at a reasonable distance; (4) that the quality of daylight should be approximated as nearly as possible in the artificial lighting of the museum.

The other unique feature of the present installation is the accomplishment of the last of the above four desiderata in the artificial lighting of the museum. Recently the importance of the quality of light in its influence on paintings and other colored objects has become generally appreciated, and the practical availability of "daylight" artificial sources has been rendered possible. The museum has been lighted almost throughout with Mazda C-2

lamps which produce an illumination similar to that of daylight.

In Fig. 1 is given the general floor plan of the museum as a basis of reference in the following detailed reports of the installations provided for the various rooms.

Rotunda.—The *rotunda* is located centrally with respect to the exhibition rooms. From the standpoint of artificial illumination, it presents a somewhat difficult problem since it is open to rooms on four sides, and each of these four adjacent rooms is distinctive in character. The *colonial room,* on the north, is a square exhibition room, lighted from the top to a relatively high intensity. On the east, the *armor court* is a much larger room with a considerably larger sub-skylight proportionately, and lighted to a somewhat lower intensity than the *colonial room.* On the west is the *garden court* which is lighted as an outdoor area and therefore to a comparatively low intensity. The south side opens to the main entrance which is not lighted brightly and where daylight quality of illumination was not employed.

In order to avoid the effect of wide contrasts of intensity and color, it was thought best to illuminate the rotunda to an average intensity, and to an average color effect with respect to the surrounding rooms. It appeared desirable for this room, in addition to obtaining a fair average intensity and color effect, that the lighting be done without any visible high brightness sources, and that the dome be lighted to an even and low brightness, taking particular pains to avoid strong patches of light along the cornice, the common fault where cove lighting is used. In the center of the dome is a circular sub-skylight 14 ft. in diameter which permits of getting a considerable flux of light into the room with no bright sources visible. The cornice all around the room was constructed in a manner that permitted the placing of lighting units at any desired point along its length about the room. The architect's plan included also eight ornamental bracket units.

The lighting of the rotunda was accomplished by directing the main flux of light through the circular sub-skylight; nine 150-watt Mazda C-2 lamps with X-ray reflectors No. 710 were placed, one in the center and eight on a circle of 4 ft. radius. In addition, sixteen small Mazda C-2 lamps were installed in the cove and spaced, as shown in Fig. 2. The X-ray reflector No. E-65 was chosen as being the most suitable for giving the uniform illumina-

tion of the dome. The placing of these cove units so that they themselves would be invisible presented a problem, for certain portions of the cornice may be seen from far distant points in surrounding rooms. It was necessary also to use care in locating the cove units in a way to avoid incongruous shadows on the walls and dome. A reference to the photograph of this room (Fig. 3) will give some idea as to the many existing projections of various kinds, which are capable of producing a multitude of undesirable shadows from sources not carefully placed.

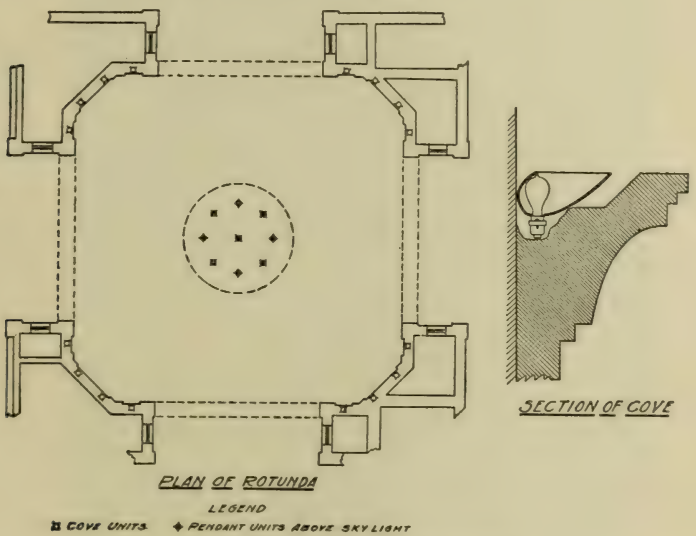

Fig. 2.—Installation of lamps in the cove.

Regular Mazda lamps of small size furnish the low brightness in the ornamental side brackets. They are not depended upon to furnish any part of the illumination of the room, being primarily a part of the architect's design, but are utilized in the lighting to good advantage in producing a warmer effect than would be obtained without them. Since the *rotunda* has less skylight than the adjacent galleries, the use of a few visible sources of light seems especially appropriate. The effect in the galleries is that they are brightly lighted from the sky, while in the *rotunda* there is a feeling that it would be dark without obvious artificial lighting. The dome is finished in a warm color, and contributes toward a warm effect. The result is that even

though the light falling on the exhibits and on the floor of the rotunda is practically of the same color quality as that used in the other exhibition rooms, the general effect is warmer than in the adjoining rooms.

A pleasing effect is obtained in the daytime although no special means is provided for the control of daylight. The circular sub-skylight covers a small proportion of the floor area and does not let in an excessive amount of daylight. The surrounding rooms contribute considerably more than half of the total light received in the rotunda in the daytime.

Illumination and Brightness Measurements (artificial lighting).

Average illumination 5 ft. above floor, 1.5 foot-candles
Wall brightness 0.3 millilambert
Floor brightness 0.7 and dome brightness 0.9 millilambert
Reflection coefficients; floor 41 per cent., wall 42 per cent.

Top-lighted Paintings Galleries (Fig. 1, Rooms Nos. 6, 7, 8, 9, 10).—These galleries are 33 ft. in width and of various lengths, aggregating 230 ft. They contain no windows but natural daylight illumination is provided by a sub-skylight 24 ft. above the floor. The glass for the roof skylight had been chosen and already installed before the Lighting Committee was appointed. This is also true of various architectural features, which are directly or indirectly related to the lighting, such as the area of the sub-skylight opening and the character and position of the structural beams in the attic space. The committee was concerned with the control of the natural daylight illumination as well as with the design of the artificial lighting system. It was the aim of the committee to accomplish the following desiderata:

(1) That the brightness of the floor and ceiling should not be disproportionately large in comparison with the brightness of the walls.

(2) That the amount of downward light should not be disproportionately large in comparison with that directed toward the important wall space.

(3) That there should be no opportunity for the reflection of bright portions of the skylight from the glazed pictures into the eye of an observer standing at a reasonable distance from the pictures.

Fig. 3.—The Rotunda.

Fig. 6.—The louver system.

Fig. 7.—Daylight illumination of gallery 8.

(4) That the quality of daylight should be approximated as nearly as possible.

It was necessary to conceal all controlling and lighting apparatus in the attic space in order to preserve the beauty of the rooms as a whole. This requirement eliminated from consideration various schemes that have merit. In order to direct the light from the attic space through the sub-skylight glass, the latter could not be of the so-called diffusing type. On the other hand, it could not be transparent without revealing to the observer the network of structural beams, which were inconveniently close to the sub-skylight, and also the controlling and lighting apparatus. Furthermore, the sub-skylight was so extensive in area that the application of simple optical laws disclosed the fact that if the glass was of the diffusing type, and thus became a bright secondary source when illuminated, there would be great annoyance due to lack of fulfillment of desideratum (3). Thus it became necessary to consider the character of this glass very carefully. It was necessary to use a glass which transmitted no rays of light without changing their direction slightly although the general direction of the beam must not be altered. An irregular crystal glass was chosen which fulfilled the following requirements: (*a*) it concealed the beams, etc., in the attic space, so that in the daytime the ceiling presented a fairly uniform appearance; (*b*) it eliminated any unavoidable irregularities in the illumination on the walls; (*c*) it minimized the brightness of the sub-skylight by minimizing the amount of light re-emitted by the glass as a secondary source. It is readily seen that requirements (*a*) and (*c*) are such that it was necessary to effect a compromise in selecting the glass. In doing so requirement (*a*) was satisfied first and then (*c*) was considered. It was necessary to use a wired glass but owing to the irregular surface of the glass chosen the wire is not easily distinguished by an observer standing on the museum floor.

Regarding natural daylight it was the aim (*d*) to control the intensity which varies enormously throughout the day and year; (*e*) to preserve a balance of illumination on opposite walls; (*f*) to decrease the excessive downward light; and (*g*) to eliminate the rake of the sun.

For controlling daylight and accomplishing the foregoing de-

siderata, a system of adjustable metal louvers was designed and installed close to the roof skylight. These are operated by electric motors remotely controlled by means of switches placed at convenient points in the galleries. The louvers, which are shown diagrammatically in Fig. 4, are divided into two units for each gallery. The unit on the left side of the roof permits light to

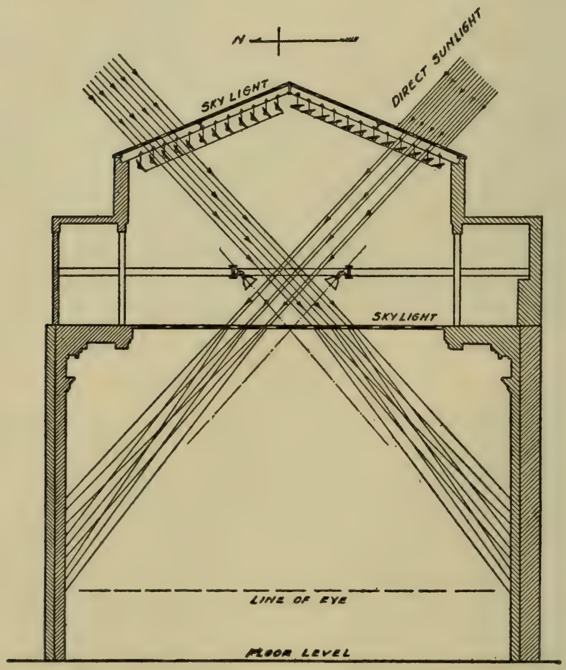

Fig. 4. Details of adjustable metal louvers.

proceed directly toward the wall on the right side of the gallery and yet does not permit much of the light from the sky or sun to reach the floor of the gallery directly. Each unit is operated by individual electric motor-control, the details of which are shown in Fig. 5. It is possible to operate the louvers either forward or backward in order to obtain the proper position.

The individual louvers are 16 in. wide and are hung 12 in. apart thus providing over-lapping which makes it possible to obtain a proper intensity of illumination on the pictures without a strong vertically downward component. Obviously the ratio

of the width of the individual louvers to their distance apart could have been realized throughout a wide range of dimensions; however, another factor entered the problem, namely, the desirability of being unable to distinguish the louvers and the clear strips of sky between them when the louvers were open. By reducing the width of the louvers and their spacing by the same percentage they would become so small finally that the bright and dark strips would be unresolved when viewed through the sub-skylight glass. For practical reasons the dimensions were made as large as possible without sacrificing this desirable feature. Certain

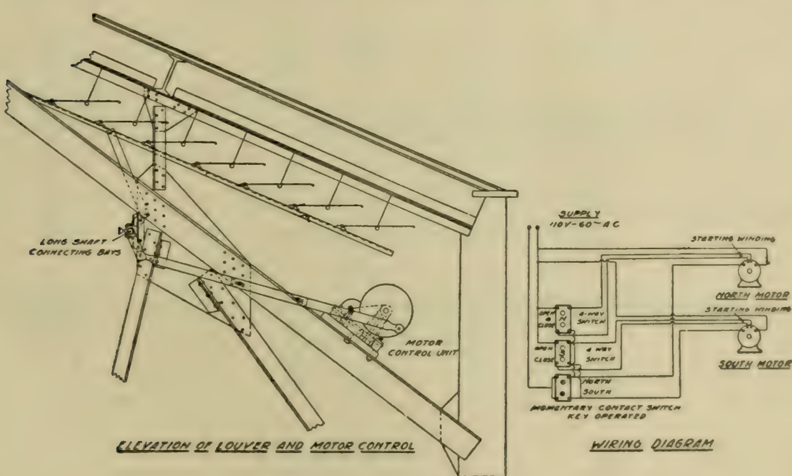

Fig. 5.—Motor control system.

lines in Fig. 4 represent rays of light and by means of this diagram the foregoing points are illustrated. A photograph of the louver system is shown in Fig. 6. In Fig. 7 is shown a daylight view of gallery 8 with the louvers adjusted to give a proper illumination intensity and uniformity.

In order to approximate natural daylight as closely as is economically possible at the present time Mazda C-2 (daylight) lamps were used thus accomplishing desideratum (4). It was found most feasible to accomplish desideratum (2) by using projector units (X-ray reflector No. 800) placed above the subskylight as shown in Fig. 8 (see also Fig. 4). A special holder (see Fig. 9) was designed by means of which it was possible to

adjust each unit to the desired angular and focal positions. One lighting unit was provided for each 3 ft. or 4 ft. of wall-length. In order to obtain satisfactory uniformity of illumination on the

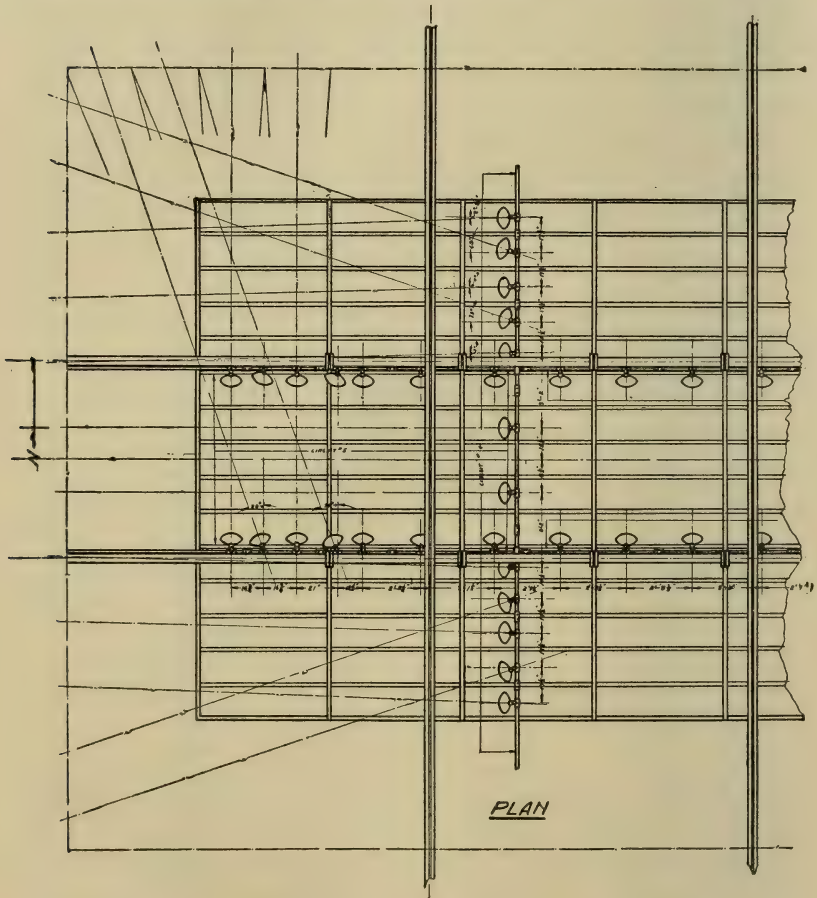

Fig. 8.—Location of projector units above sub-skylight.

principal wall area it was necessary to adjust the units very carefully, therefore the lamps, which were 150-watt Mazda C-2, were eventually slightly frosted with an etching solution so that this difficulty would not confront those responsible for the maint nance of the installation. The same result could be obtained by using a sub-skylight glass having a slightly more spread trans-

mission, but this would also increase the brightness of the glass which it was the aim to minimize.

A photograph of the artificial lighting installation is shown in Fig. 10 and one of gallery 8 under artificial illumination is shown in Fig. 11. The scoops, shown in Fig. 10, were attached to the reflectors in order to intercept the direct light from the lamp. Many details such as painting the louvers, beams and walls in the attic space were carried out with the object of making the whole as pleasing in appearance as possible. Throughout the work it was necessary to distinguish between illumination and its effect, namely brightness,—a distinction too often neglected.

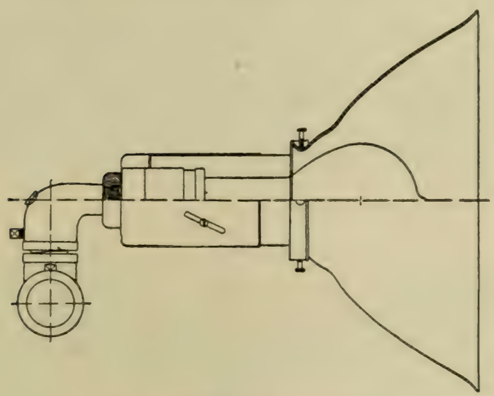

Fig. 9.—Adjustable lamp holder.

The measurements of daylight illumination were made on a clear day when the intensity and distribution of natural light were fairly constant during the period required for completing the observations in a given room. In the top-lighted paintings galleries the distribution of light obviously depends upon the positions of the louvers and for the daylight test these were set by the museum authorities and the resulting lighting conditions appeared sufficiently satisfactory to be considered representative for test purposes. It is of interest to note that in this case the illumination intensities on the opposite walls as adjusted by the louvers were found to be within 10 per cent. of each other. Measurements of illumination and brightness were made on the principal wall space and on a horizontal plane 5 ft. from the

floor. Average results in foot-candles for natural lighting, with the louvers in the position considered satisfactory, are shown in Fig. 12. Point *d* was on the north wall (which received direct sunlight unless intercepted by the louvers) and point *d′* was on the south wall which does not receive direct sunlight under any condition. Obviously on a clear day the south bank of louvers is closed considerably more than the north bank. It should be noted that the south louvers control the illumination on the north

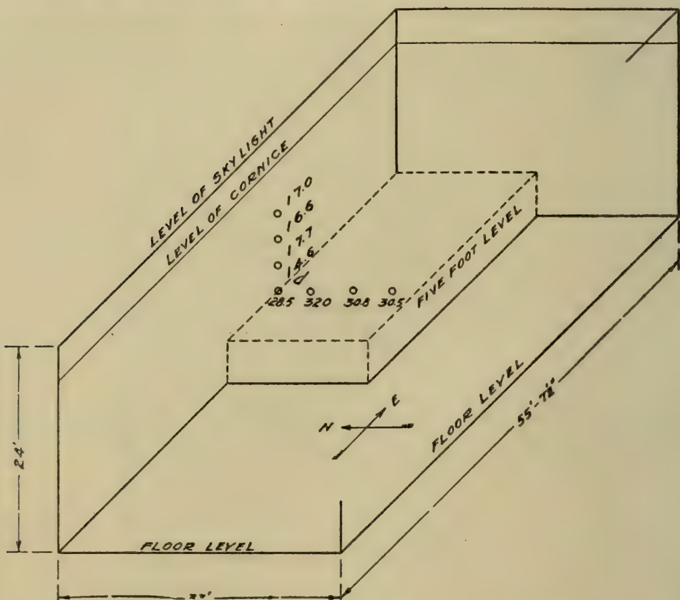

Fig. 12.—Intensities of illumination; natural lighting.

wall and the north louvers that on the south wall. Both sets reduce the amount of light reaching the floor. Inasmuch as in such a room in the daytime, relative illumination intensities are of chief interest, it is interesting to note that on a clear day the south wall, which receives no direct sunlight approximately represents the results that would be obtained on an overcast day on any wall in the room. It is also noteworthy that the brightness of a clear blue sky is less than that of most overcast skies and that it is safe to assume that it is even less bright than an average overcast sky. It is seen that on this day the illumination intensity on a horizontal plane 5 ft. from the floor is less than twice as great as

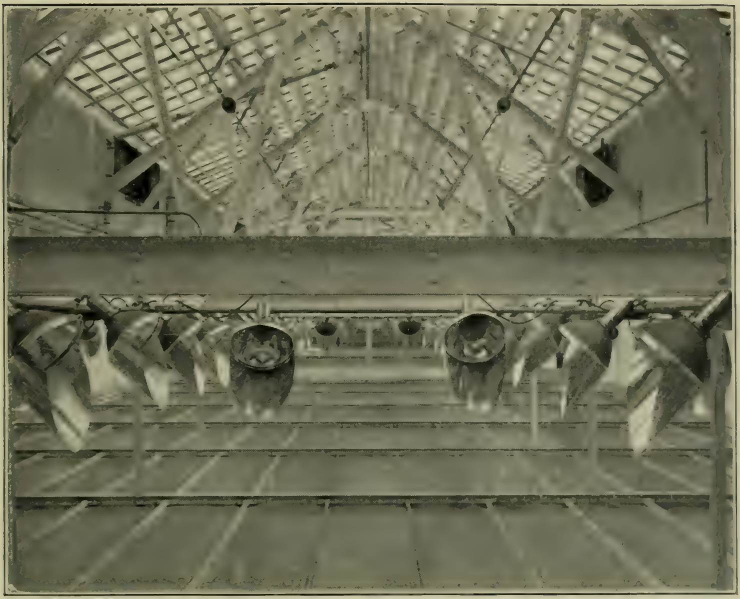

Fig. 10.—Artificial lighting installation.

Fig. 11.—Artificial illumination of gallery 8.

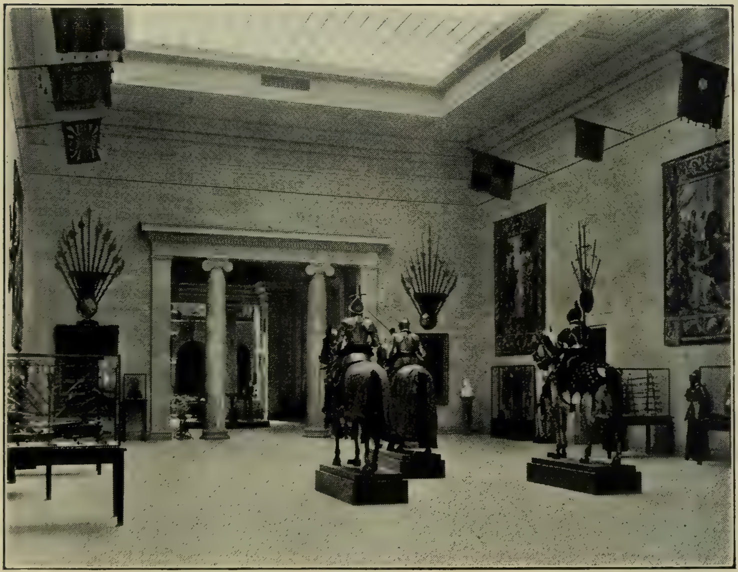

Fig. 14.—Court of Tapestries and Armor.

that on the wall space where pictures are normally hung. This is considered as highly commendatory of the louver system because, if an ordinary diffusing sub-skylight had been used, this ratio instead of being two would have been many times greater. Computation shows that this ratio might be easily as high as twenty for an ordinary sand-blasted glass if no louvers or other controlling devices were used as is the case in many galleries.

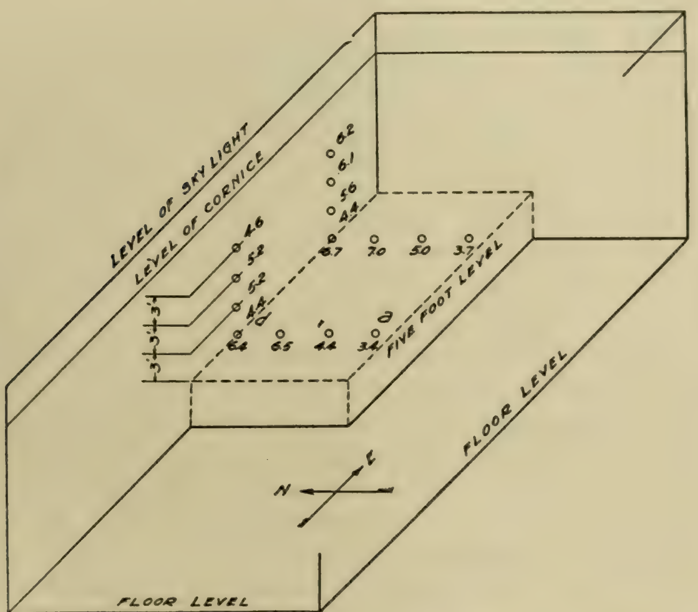

Fig. 13.—Intensities of illumination in gallery 8; artificial illumination.

In order to show the ability of the louvers to control the ratio of the illumination intensity on the horizontal plane (5 ft. from the floor) to that on the walls, the louvers were varied in position and at the end of each 5 seconds, during which the louvers were being electrically operated, illumination measurements were made at *a* (horizontal plane), at *d* and at *d′* (vertical plane). These data are presented in Table I. It is seen that the illumination intensity at *d* decreases to about one-sixth of the maximum value, at *a* to about one-fifteenth of the maximum, and at *d′* to about one-third of the maximum. The ratios of the horizontal

illumination at *a* to the vertical illumination at *d*, and also to that at *d'*, are shown in the fifth and sixth columns respectively. It is seen that this ratio varies greatly. The smaller values are the more desirable. It will be noted that inasmuch as the ratios *a/d* and *a/d'* are controlled separately and that their values (columns 5 and 6, Table I) are small and equal at certain positions of the louvers even on a sunny day, the chief aims of the louver system have been realized.

TABLE I.—EFFECT OF OPERATING THE LOUVERS.

Time sec.	Illumination in foot-candles: *d* (north wall)	*a* (5 ft. horizontal plane)	*d'* (south wall)	Ratios: *a/d*	*a/d'*
0	80	368	25	4.6	14.7
5	72	298	23	4.1	13.0
10	55	196	21	3.6	9.3
15	34	75	19	2.2	3.9
20	17	35	12	2.1	2.9
25	14	26	11	1.9	2.4
30	13	24	9	1.8	2.7

In Fig. 13 a brief summary of the measurements of artificial lighting results in gallery 8 is presented. The numbers on the diagram indicate intensity of illumination in foot-candles and it is seen from these that certain desired results were obtained.

Court of Tapestries and Armor.—The *court of tapestries* and *armor* (Fig. 14) is the largest and beyond question the most impressive of the galleries in the museum. The gray stone walls hung with banners and tapestries form a fitting background for the horsemen and guards in armor, and it is, designedly, the complete picture rather than the detail of individual exhibits which first arrests the attention. In this room therefore it was deemed of primary importance to provide a system of lighting which in itself would be satisfying to the eye and harmonious with the surroundings, as well as effective in illuminating the several exhibits. To accomplish these ends, the following requirements were formulated:

(1) That the sub-skylight should present an appearance of uniform brightness both by day and by night.

(2) That the intensity in all parts of the room where exhibits are located should be at least of the order of 2 foot-candles.

(3) That the maximum intensity of illumination should occur

in the central portion of the room to accentuate properly the group of horsemen which forms the principal object of interest in the court.

In the effort to fulfil the first requirement, the use of opal glass was considered, but later dismissed, primarily because a diffusing medium of this character would have revealed on its surface a distinct shadow of every member of the steel roof trusses when illuminated either by natural or artificial light. It was necessary, however, to choose a glass which would break up the light rays to a considerable degree and it was found by experiment that when the somewhat uneven surface of commercial wired glass was deeply etched the diffusion was sufficient so that a uniform brightness of the skylight could be secured and at the same time the shadows of the beams were not visible. A laboratory test on samples of the glass showed the maximum allowable spacing between lamps to be one-third their height above the sub-skylight, if the location of individual units was to be completely obscured. The possible mounting height of units was limited to an average of 9 ft., but as the skylight would seldom be viewed perpendicularly, it was thought permissible to extend the spacing to approximately 3 ft. 9 in. as this made possible a symmetrical arrangement of outlets relative to the beams and trusses. The dimensions of the skylight are 30 ft. by 72 ft., hence eight rows of twenty units each were required to illuminate it and in addition sixty outlets were provided beyond the edge of the skylight and completely surrounding it to preserve the appearance of uniformity to the outermost panel of glass, even when viewed from the opposite side of the court. From the location of units, Fig. 15, it is evident that a very much smaller percentage of the light flux from the outside rows of lamps will find its way through the skylight than in the case of the lamps more centrally located. From the standpoint of efficient lighting therefore it became desirable insofar as possible to place large units over the center of the area and this was also in accordance with the third mentioned requirement. Thirty-two of the central outlets were each equipped with 150-watt Mazda C-2 (daylight) lamps and concentrating mirrored glass reflectors (X-ray No. 710). These outlets were depended upon for the greater part of the illumination and the remaining outlets were

therefore equipped with distributing reflectors (Ivanhoe BED-60) and the smallest size of daylight lamps obtainable. The intensity of illumination on a horizontal plane varies from 5 foot-candles

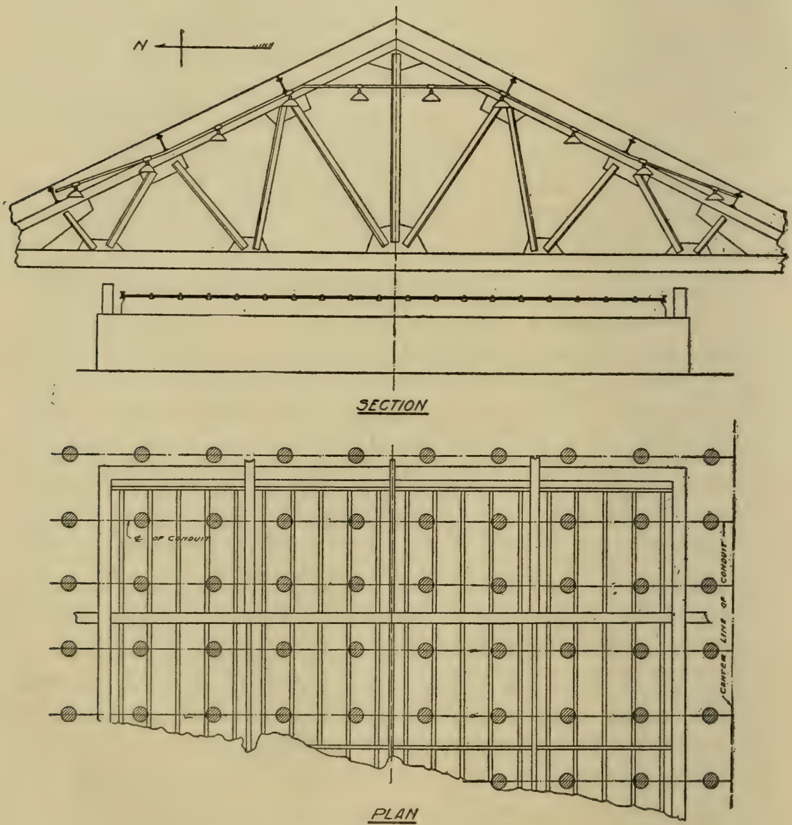

Fig. 15.—Location of units above skylight.

in the center of the room to slightly less than 2 foot-candles near the corners.

No provision was made for controlling the intensity of daylight illumination in the court other than by applying water color paint with an air brush to the upper skylight once each summer. The intensity on clear days is therefore considerably higher than necessary—from 123 and 109 foot-candles on the north and south walls respectively, to 168 foot-candles on the floor—but owing to

the low ceiling height of the attic space, in comparison with that in other top-lighted galleries, a much better ratio between the brightness of walls and floor is maintained here than was the case in the paintings galleries before the louvers were installed. Louvers over this court would be desirable principally from the standpoint of ready control of the average intensity of illumination.

As previously stated the shadows of beams and trusses are not distinguishable on the sub-skylight, neither are the beams themselves visible through it, but from some points of view, the location of trusses can nevertheless be detected due to a faint silhouetting against the bright background of the lamps or the upper skylight as the case may be. To eliminate this effect it is proposed to fill in the space between the truss members with asbestos board which, it has been demonstrated, will entirely eliminate the effect of silhouette.

Colonial Room (Fig. 4, Room No. 1).—Architecturally, among the exhibition galleries, the colonial room stands second only to the *armor court.* It is used as its name implies for the exhibition of paintings of the colonial period; of statuary, and of smaller articles in cases. The walls of the room are blue and the ceiling is a light buff color. The ceiling is coved from the cornice to the edge of the skylight which covers about one-fourth of the floor area of the room.

The attic space above this gallery is irregular in shape and the upper skylight limited in area, therefore to preserve a satisfactory appearance it was desirable to choose for the sub-skylight a glass of good diffusing properties. However, opal glass was out of the question for the same reason as in the armor court and furthermore light transmitted through a horizontal opal plate would not give a distribution well suited to lighting the side walls which as has been pointed out were far removed from the edge of the skylight. Heavily etched plate glass in small panels, unwired, was finally chosen as the most satisfactory compromise and proved entirely satisfactory when installed so far as daylight illumination was concerned.

In the case of the artificial lighting on the other hand, the fact that differences in intensity are readily discernible on sand-blasted glass prohibited the use of projector units such as

those specified for the top-lighted paintings galleries. At the same time it was extremely desirable to choose units having a light distribution which favored the walls, and a prismatic reflector (Holophane No. 595) was finally secured which when used in a pendent position with a Mazda C-2 lamp gave a distribution curve of the form indicated by Fig. 16. Since the room to be lighted was square this distribution when modified somewhat by the sand-blasted glass proved decidedly advantageous. Twelve 600-watt Mazda C-2 lamps were required for the installation and the units were placed as shown in Fig. 17. The height of the lamps and their position were in each case determined to within ½ in. by a preliminary trial installation.

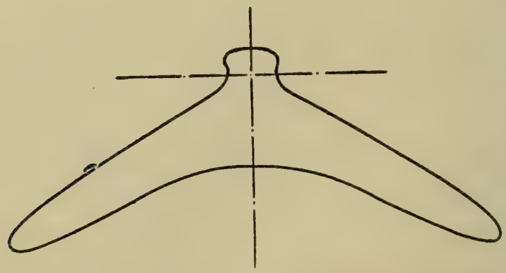

Fig. 16.—Distribution curve of reflector and lamp.

The slightest deviation from the position chosen would have produced unsightly shadows of the trusses on the glass of the skylight. Fig. 18 gives a summary of the artificial illumination and brightness measurements which were made in this room. It will be noted that the intensity illumination in the center of the room is relatively higher than in the top-lighted galleries devoted exclusively to the exhibition of paintings. This is due in part to the different method of lighting, but in larger measure to the blue wall-covering at present in use in the colonial room, which while it does not appear dark in color, nevertheless has an absorption for the light from Mazda C-2 lamps of approximately 80 per cent.

Near-east Room (Fig. 1, Room No. 12).—The near-east room is similar to the other side-lighted galleries (q. v.), but instead of

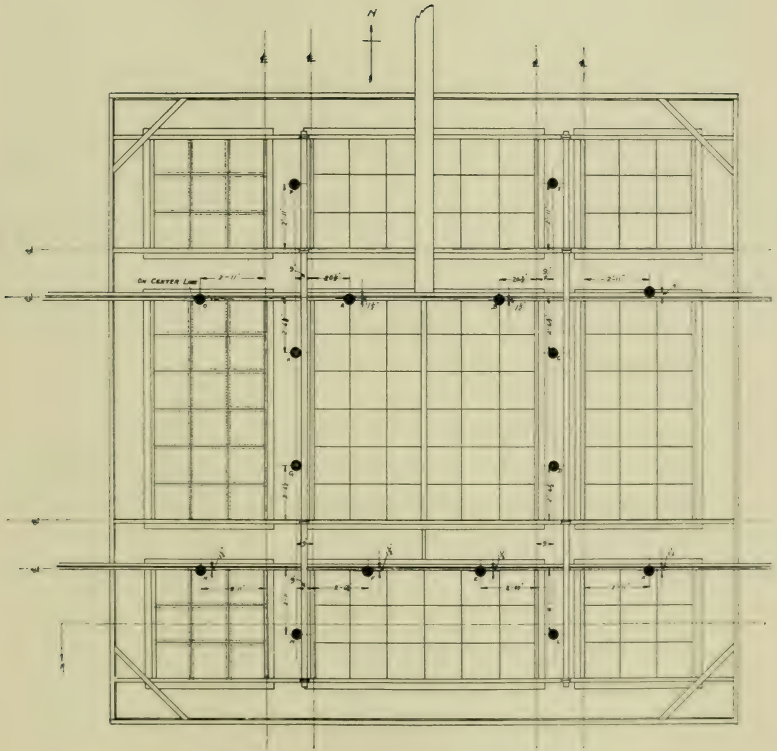

Fig. 17.—Location of units in Colonial Room.

Fig. 19.—Natural lighting of garden court.

Fig. 20.—Gallery 3 under artificial lighting.

a plain beam ceiling it has a dome covering about one-half the area of the room. This dome has a small circular skylight opening in the center. The director of the museum hopes to obtain some old lanterns appropriate for hanging in this room; and when the lanterns become available it is expected that they can be made into combination direct and indirect lighting units and used to furnish satisfactory illumination. It was considered best to provide a temporary system of illumination which would serve

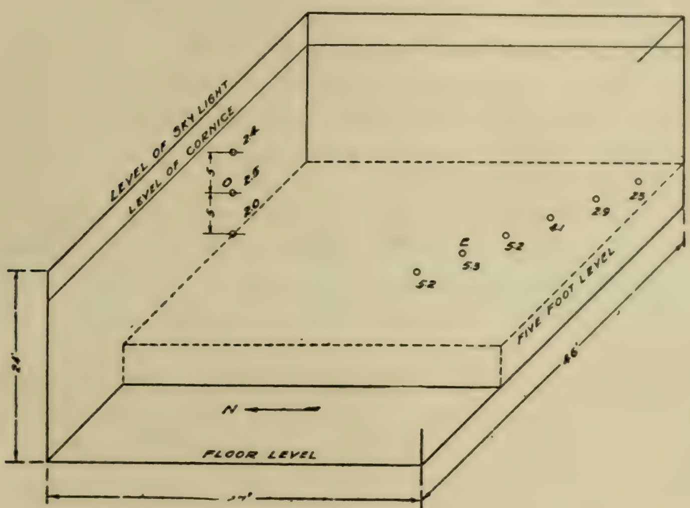

Fig. 18.—Intensities of illumination in Colonial Room.

until suitable lanterns could be obtained. Four Holophane "Realite" units were hung on outlets which had already been provided, located around the rim of the dome, with a small amount of light above the small skylight opening merely as a means of avoiding the appearance of a dark hole at the top of the dome.

The near-east room is lighted in the daytime by a single north window. Excessive window brightness has been eliminated by the installation of a decorative inner window covering consisting of panels of transparency designs.

Holden Gallery (Fig. 1, Room No. 4).—The lighting of the *Holden gallery* was arranged by the designer of this room. Four

ring chandeliers, each having eight outlets, have been put in place. The Lighting Committee was able to render some assistance in the choice of globes and lamps for these fixtures. The designer of this room employed dark wall covering, and relatively dark ceiling finished in warm tones. It seemed desirable, if possible to obtain the warm effect desired by the designer, and at the same time to have the light falling on the pictures to be of the same daylight quality as used in the other galleries. This was accomplished by using Mazda C-2 lamps in slightly diffusing globes which had been covered with a light yellow coating. The lighting units present a warm appearance due to the fact that the diffused light has undergone a series of reflections while the main portion of the light comes direct from the filament by a single transmission through the yellow coating, and is not modified in color to any considerable extent.

This room is of the same size as the near-east room and is lighted in the daytime by a single north window. Window brightness is reduced in the same manner but with an inner window of a design to conform to the special treatment of the room.

Garden Court.—In the artificial lighting of the *garden court,* it was decided to produce the effect of an outdoor garden at night. To produce this effect the sub-skylight could not, of course, be utilized as a transmitter of light. It is necessary to have the ceiling as dark as possible. The main lighting is accomplished with four lantern units on posts, placed symmetrically, as may be observed in the daylight photograph (Fig. 19). The lanterns have a strong horizontal and downward component, with a relatively small amount of flux in the upper hemisphere. The lanterns are panelled, making it possible, by choice of glass, to reduce the brilliancy of the units in any desired directions. As installed, these are provided with dense glass on the sides which most often come into the line of vision of visitors passing through the court. 300-watt Mazda C-2 lamps are used in these units.

The loggia, on the west end of the garden court, is illuminated from overhead to an intensity higher than that prevailing in the court. The light comes from an antique lantern hung in the central arch. This old lantern was obtained as an exhibit for the

museum, but now has the second function of serving as one of the active lighting units.

Special provision is made for the illumination of the central fountain. With a lighting system to give the desired night effect in the court, it was difficult, without special provision, to avoid the appearance of a dark basin. This special illumination is obtained from above the skylight, directly above the fountain, by means of a lens system such as is used in the ordinary stereopticon lantern. An aperture of the exact shape of the fountain is cut in an opaque slide placed with respect to the lens system so that it can be focused by an objective to exactly cover the area of the fountain. By this means it has been possible to provide illumination with an absolutely sharp line of demarcation and from an entirely concealed source.

In the daytime the court is lighted to very high intensity. The sub-skylight is in the same class as the upper skylight, a wired glass having a slightly spread transmission characteristic. Since the skylight covers the entire area the quality of light received in the daytime is comparable with that of outdoors. The high intensity in the daytime is necessary for the proper growth of the plants in this court, and results in the desired effect, namely, that of an *outdoor* court.

Other Exhibition Rooms (Fig. 1, Rooms Nos. 2, 3, 5, 11, 13, 14, 15).—Most of these rooms, whose locations are shown in Fig. 1, receive light from large windows on the north side. Side-lighted galleries are well placed on the north side of a museum because the difficulties which attend the entrance of direct sunlight on other exposures are absent in this case. The natural light is controlled in intensity and quality by draw-curtains of a slightly yellowish tint which were installed by the museum authorities. The desiderata regarding artificial lighting applied to these rooms were somewhat different from those in the top-lighted galleries. For instance, a fair intensity of illumination is desired on the floor and on the normal horizontal plane owing to the necessity of lighting objects and cases distributed about the rooms. Paintings, tapestries, etc., are hung upon the walls so that the walls must be illuminated sufficiently.

Any consideration of semi-indirect and indirect systems of lighting was ruled out because of the possibility of decorating

the ceilings at some future time with rather pure colors. These rooms are plainly finished and the exhibits are more or less transient so that an enclosed prismatic unit of extensive distribution was adopted as meeting the requirements satisfactorily. The dimensions of these rooms were such that four units were used in the smaller rooms and eight in the large one, gallery 3.

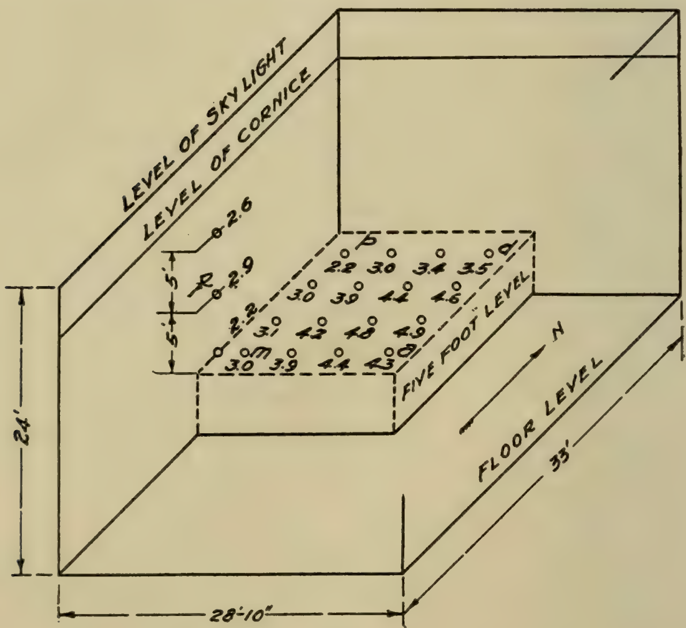

Fig. 21.—Illumination intensities in side-lighted gallery 2.

In fact, disregarding the dividing walls, the units were arranged in two rows parallel with the length of the building for galleries 2, 3, 13, 14, 15. In galleries 5 and 11 similar conditions prevailed, but the rooms being narrower, required only one row of units, there being three installed in each room. 300-watt Mazda C-2 (daylight) lamps were installed in all these units with the exception of the four central units in gallery 3 in which 150-watt lamps were used. An idea of the natural lighting condition and of the type of artificial lighting unit can be gained on referring to Fig. 20 which is reproduced from a photograph of gallery 3.

The illumination results obtained in side-lighted gallery 2 are shown in Fig. 21. These are representative of the results in all side-lighted galleries.

The Lighting Committee of the Cleveland Museum of Art, which submitted the above report to the Building Committee of the Museum, was as follows:

E. P. HYDE, *Chairman*,
W. V. BATSON,
S. E. DOANE,
E. J. EDWARDS,
WARD HARRISON,
M. LUCKIESH,
J. A. MACLEAN,
W. R. MCCORNACK,
F. A. WHITING.

DISCUSSION.

G. H. STICKNEY: Under daylight conditions when the north wall of a room is illuminated by South light, and the South wall by North light, considerable difference in the apparent color of the walls is sometimes observed. Was such a color difference observed in this instance, and if so, were steps taken to minimize it?

In the artificial lighting of a top-lighted gallery it is certainly desirable, wherever practicable, to place units above the inner skylight and arrange them so as to direct the light toward the walls. Not only can a better lighting effect be obtained, but the appearance of the room without fixtures is much finer. It seems almost impossible, in such a room, to provide fixtures and place them so as not to detract from the appearance. Some experiments, made at the Buffalo and Boston Museums, about ten years ago, showed that with certain arc lamp equipments employed, about four times as much light was necessary when the lamps were placed above the skylight, as when they were hung below. With the more modern equipments used in the Cleveland Museum of Art, I judge the ratio would not be quite so high. The difference in economy, unfortunately has compelled a number of art museums to light from below, but I believe the additional expense

is warranted by the improved effect whenever the funds are available.

The direction of light has quite an effect on the appearance of the paintings. Top lighting seems generally preferred; I presume because it corresponds to the prevailing direction of light under which the artist works. There are some paintings, however, which show up better under lighting from one side. In recognition of this, the Boston Museum provided some side-lighted galleries, and they were quite particular to hang the paintings so as to receive the light from the proper side.

It is rather difficult and expensive to reproduce such a daylight direction in artificial lighting, and at the same time provide sufficient intensity in the more distant parts of the room. It has been suggested that the effect be obtained by indirect lighting, utilizing opaque white window shades as reflectors. So far as I know, this method has not been used, and most galleries have abandoned the effort to produce the effect. Practically all the side-lighted galleries receive their artificial illumination from distributed units suspended from the ceiling. Beside the poor directive effect this method of lighting very often gives reflected images in the cover glasses of the paintings, or even in the paintings themselves. To avoid this, usually trough lighting or totally indirect lighting has been used.

W. O. Morrow: I would like to say that I am with the company of which Dr. Hyde spoke. We make "ventilighters," or adjustable louvers similar to those used to control the daylight in the top-lighted painting galleries of the museum. We have an installation at the Lecture Course rooms at the university, where the controlling of the daylight under those conditions may be illustrated. In the model the steel vanes are represented by glazed cloth owing to the ease of transportation. We are handling almost the identical conditions as in the museum at the art gallery of Mr. Breckenridge Long in St. Louis and we are confident it will prove equally successful. We also make the system with louvers of a diffusing cloth, which is its most general use, and is a ventilating, shading devise adaptable to any skylight or window giving the maximum amount of light without glare and allowing almost free circulation of air.

M. LUCKIESH: Mr. Stickney brings up the question of the difference in color of the light illuminating the various walls owing to the difference in color of direct sunlight and of skylight. This difference in color is very noticeable in comparing north and south rooms because the former receive no direct sunlight and consequently appear considerably bluer or colder than rooms with southern exposure.

In the top-lighted paintings galleries where the direct sunlight is prevented from falling directly upon the wall by the louvers the difference in the color of the light upon various walls is greatly reduced. The intercepted sunlight is scattered more or less and some of it finds its way to each of the walls. On overcast days there can be little or no color-difference and on clear days this is minimized by the louver control. Although there is no general agreement, I favor southern exposure for paintings' galleries and I believe this quality of daylight is preferred by the majority of those who have studied the lighting of paintings.

Although this is the first large museum which has been lighted by means of artificial daylight it should be mentioned that a number of smaller galleries and exhibits have been lighted by means of the same type of lamp heretofore with success.

A point of interest in connection with the quality of light is the color of the walls. Indoors, especially at night, we usually surround ourselves with the warmer tints and shades. In applying artificial daylight at night an objection is often raised regarding its coldness. The important objects, such as paintings or goods on display in show windows, can be lighted by means of artificial daylight with great satisfaction if the background is kept in warm colors. In fact, the impression of warmth or coldness which we gain from a certain view is influenced largely by the color of the overwhelming area of the background, especially in such cases as paintings' galleries. The gold frames also add to the impression of warmth. In this museum a medium shade of cream or buff monks-cloth was used upon the wall and the resultant effect was such that the impression of coldness, under the artificial daylight, at night was quite effectively eliminated. The light reflected from this background is doubtless somewhat modified, but under the conditions does not appreciably vitiate

the quality of the predominant direct light which illuminates the paintings.

WARD HARRISON: It is seen from the report that by adjusting the louvers the intensity on the walls can be varied over a wide range. In planning the system the question naturally arose as to how close the attendants in the gallery would ordinarily come to keeping the illumination on the opposite walls fairly well balanced; at one time it was even thought of installing some form of photometric device to assist in this setting. It was found, however, from actual measurement that by looking at the walls the custodian was able to gauge the proper setting of the louvers accurately enough so that the illumination on opposite sides checked within 10 per cent. Consequently it was deemed quite unnecessary to make any more elaborate provision to secure equality of brightness.

C. H. SHARP: I would like to ask a question as to the economics of using blue-bulb lamps instead of clear-bulb lamps with separate screens. The separate screens would not have to be renewed when the lamps burn out.

J. L. STAIR: In the galleries of the skylights and where the concentrating reflectors are used above the glass ceiling for directing the light against the walls on which the pictures are displayed, was any attempt made to even out the lighting of the skylight itself, making it of fairly uniform brightness? From the standpoint of appearance are the brighter areas on the ceiling objectionable?

S. G. HIBBEN: I have noticed in some cases of lighting through a ceiling similar to that mentioned by the speaker, that it was a great problem to choose the right sort of glass. I believe that in this case the glass used was of a crystal characteristic, like the ordinary transparent window glass but of a slightly pebbled or irregular surface, securing the breaking up of the light rays but not their change of direction. In the Albright Art Galleries and several others, use has been made of ordinary sand-roughed, sheet glass, and while it accomplished the same results, yet due to spots of light and poor color, the appearance of that skylight is nowhere nearly as handsome as the one we have just discussed or the one in the Soldiers' Memorial Building of Pittsburgh and several others. A skylight of that sort accumulates a

great deal of dust, and any glass of the character of crystal glass shows dark after a given time. It occurs to me that if we could secure a glass of some composition that is equivalent to crystal with an irregular surface, but yet with some white or neutral coloring matter in it, so that this accumulation of dust will not cause the skylight to appear a dark gray color, it would be a good thing.

R. FF. PIERCE: Some time ago I encountered a problem in the lighting of paintings which, while it was not parallel to the problems presented here, inasmuch as it was not an art gallery, brought forth some developments which were to me of a rather surprising nature. This was a mural painting on the end wall of the chancel of an Episcopal church at Whitemarsh. The painting covered this entire end wall and was done in distemper and very unsaturated colors. The ceiling and side wall were both very dark-colored woods and there was no opportunity to place a lighting unit in coves or any place in the side wall or ceiling; there was, however, in front of the chancel a rood-screen which formed a possible location for lighting units; so we installed behind the rood-screen a double row of lamps, inverted lamps and upright lamps, six of each, with angle reflectors, to illuminate this painting.

We probably would have experienced some glare had it not been for the fact that the painting was in distemper and had a comparatively unglazed surface. We were very much surprised at the way in which the color values worked out. The artist felt considerable concern lest color values in the paintings might be distorted by reason of the discrepancy between the light of the lamps used and daylight. We went to some expense and trouble to develop a type of mantle and provide screens which would reduce the light approximately to daylight values, if necessary, and it was very interesting to note that the ordinary commercial mantles with which the lamps were first fitted gave an effect that the artist and the committee also pronounced entirely satisfactory, and this committee was formed of members of the congregation who were people of discrimination and had been accustcmed to judging paintings. The fact that they were satisfactory was due, in large part, to the fact that the tints were very light tints and very unsaturated. If they had been saturated colors,

we possibly would have found some difficulty from color differences, but their being unsaturated minimized that and we obtained very good results from that very simple expedient.

WARD HARRISON: I would like to inquire from Mr. Pierce as to the color tone of the windows in the church to which he refers. It occurs to me that the bare gas mantle might give approximately the same color of light as that which came in through the windows, while the paintings were being made, if the latter were of amber glass.

R. FF. PIERCE: The painting was actually made in the artist's studio and afterwards transferred to the wall, but I think possibly there is something in that, that the color of light as it entered through the windows was considerably warmer than ordinary daylight.

E. P. HYDE: Replying to Dr. Sharp's inquiry regarding the economical feature of the installation, I do not doubt but that the installation would have been slightly more economical in operation if the ordinary type of lamp had been used in some kind of an enclosing unit fitted with glass similar to that used in making the lamp bulb, but daylight glass of this density is not made in plates, so far as I know, and of course it would have been very expensive to have developed it.

There are units on the market in which special glass is used in an enclosing globe or in some other form rather than in the lamp bulb, but I take it that it is not the place here to discuss the various units which have been developed or to advance the technical reasons which may have led manufacturers to incorporate the special glass of a particular density in the bulb of the lamp. It is sufficient here, I think, to state merely that the special lamp was more suitable for use in the present installation in the judgment of the committee than any other available unit.

I would reply to Mr. Stair regarding the irregular brightness of the sub-skylight by saying that we are not illuminating the sub-skylight except to a small extent. The direct flux proceeds through the skylight with but slight diffusion and falls upon the hanging walls of the gallery. In the artificial installation the direct light from the lamps which could otherwise be seen past the edge of the reflectors is obscured by the scoops shown in the photograph. It is true that as can be seen from a close inspec-

tion of Fig. 11 that the sub-skylight is not absolutely uniform in brightness under artificial illumination. There are indications of the alignment of the units above, but the non-uniformity is not objectionable; indeed one would scarcely notice it unless his attention was called to it as he is more concerned with the hanging walls than with the skylight. It was the judgment of the committee that the emphasis should be placed on securing the best possible illumination of the hanging walls, making whatever sacrifice might be necessary in the uniformity of the sub-skylight in order to produce this result.

I would like to add to the discussion a word regarding the use of what is known as a velum or artificial ceiling. I am of the opinion that paintings considered solely from the standpoint of their illumination and neglecting the artistic value of the room are best seen when lighted from a skylight or artificial units above a false ceiling or velum which is placed some feet below the plane of the sub-skylight. There is a gallery in the Neue Pinakothek in Munich lighted this way and in my judgment the result is very satisfactory. An attempt has been made to use the same scheme in one of the rooms of the Chicago Museum, but I think this should not be taken as a fair example of the method. Architects object to the use of the velum from the standpoint of the artistic value of the room as a whole and, of course, it is impossible to install a velum after a building has been designed without ruining rooms. But I consider the value of the velum from the standpoint of the proper lighting of pictures sufficient to justify a further effort on the part of architects to make a design that will be consistent with the design of the building and thus conserve both the utilitarian and the esthetic features.

ON THE EFFECT OF BRIGHTNESS OF LIGHT SOURCE ON GENERAL ILLUMINATION.*

BY F. C. CALDWELL.

The difficulties involved in estimating and comparing different degrees of illumination are well understood by those who have made a special study of the subject, but the average layman has little hesitation in passing judgment upon almost any case of illumination. Furthermore the fact that his ancestors for generations have been deciding questions of illumination for themselves gives some ground for his assumption of competency in the matter.

The investigation described in the following paper is based to some degree on the above assumption. It seeks to ascertain whether there exists any general agreement as to the relative values of bright-light-source and diffused-light-source illumination required for satisfactory general seeing. The results obtained, though not as numerous as might be desired, indicate a rather surprising ability of observers, only slightly trained in the estimating of illumination, not only to form a concept of a given light density but also to reproduce it after an interval of time. It is to be remembered that the results obtained were without any previous practice, nor did there seem in general to be much improvement with practice during the short tests made.

EQUIPMENT AND METHOD.

The work was done in a room 16 ft. 9 in. by 23 ft. 9 in. and 11 ft. 8 in. high. The walls and ceiling were white with a cream tint. The change between direct and indirect illumination was effected by the following apparatus: A wooden bar 8 ft. long is pivoted at its center on the ceiling and carries at one end a cluster of six lamps with prismatic glass reflectors, and at the other end a 6-arm indirect lighting fixture with the lamps about 38 in. from the ceiling. This is shown in Figs. 1 and 2.

* A paper presented at the tenth annual convention of the Illuminating Engineering Society, Philadelphia, Pa., Sept. 18-20, 1916.

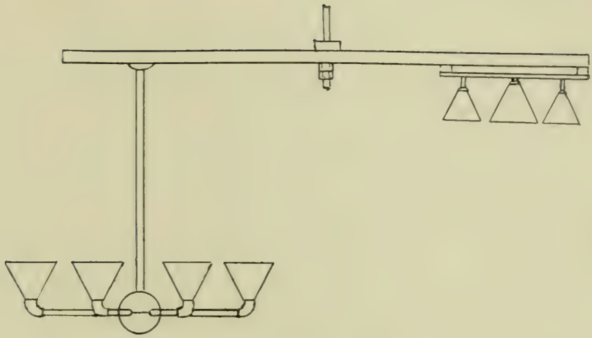

Fig. 1.—Movable arm carrying direct and indirect fixtures.

Fig. 2.—Installation of movable arm and test apparatus.

There are two of these bars, located so that the light sources when in position for use, are on the long axis of the room and 6 ft. from the end walls. This places them 11 ft. 9 in. apart and 8 ft. 4 in. from the side walls.

The six tungsten lamps of each light source as described above, include one each of the following nominal wattages, 10, 15, 25, 40, 60, and 150. The corresponding sized lamps of the two direct light-sources are connected in parallel; and the same is true for the indirect units. One side of all the lamps of the direct sources are connected together and brought to a switch on the switchboard shown in the lower left hand corner of Fig. 2. The same is done for the lamps of the indirect sources. The other sides of all four lamps of like candlepower are connected to a single switch on the switchboard.

By means of the above equipment either the clusters of prismatic-reflector lamps or the indirect fixtures can be placed on the center axis of the room. Then by operating the two switches which control all the lamps of each system, direct or indirect illumination can be obtained; and by means of the individual switches connected to each pair of like lamps, a wide range of light values varying by small steps is available. The prismatic reflectors are of the intensive type and located about 10 ft. 8 in. above the floor. One group is nearly in the plane of vision, but the angle is such that the filaments are nearly all concealed. The other cluster is at about 90 degrees from the line of vision, the filaments being for the most part visible. The observer was cautioned not to notice the arrangement of lights lest this affect his judgment of the illumination values. The whole time required to change from one form of illumination to the other was approximately 30 seconds.

As a field of observation, a table covered with a white cloth was placed near one corner of the room and on it, were grouped a collection of books, magazines, a clock, a voltmeter, a cigar box and other objects. The observer was asked to include this table with its contents generally, in his estimate of the illumination value.

The procedure finally adopted, after some experimentation, was as follows:

The observer was placed diagonally across the room from the table full of objects, which he was to observe. A certain indirect illumination was established, the appearance of which he was instructed to fix in his mind, taking time to adjust his eyes to the light. When he was satisfied that he had a good impression of the illumination he closed his eyes and the direct was substituted for the indirect illumination, but was given a much lower value. After opening his eyes, the observer gave instructions for the raising of the illumination by the operator, till in his judgment, it was equal to the former indirect value. The operator then noted the switches in use and after the observer had again closed his eyes, exchanged the direct for the indirect units. Starting again with a low value, the estimation of the equal indirect illumination was proceeded with as formerly in the case of the direct. This procedure was repeated once more for the direct and again for the indirect, thus giving the order, indirect—direct—indirect—direct—indirect. There were thus two changes from indirect to direct and an equal number from direct to indirect. This series of five observations was then repeated with the variation that a higher value of illumination, instead of a lower was used to begin each observation. In some cases there is observed a tendency to drift; for instance when the start is made with a low value the observer is satisfied each time with a lower final value. On the whole, however, the results obtained show rather a surprising absence of this effect.

The illumination values were determined by a Macbeth illuminometer, the screen disk being placed horizontal and 4 in. above the top of the table. The illumination for each lamp was measured and then a table for all combinations of lamps constructed by adding the component parts. Great refinement is of course unnecessary in a test of this kind.

Observers A to F, whose readings are recorded in the following table (Table I) were physicists or electrical engineers and, while with one exception not special students of illumination, they were familiar with its principals and accustomed to making accurate observations. Observer G was a 12-year old girl. There was one other observer, a student whose readings were so erratic as to make them valueless.

TABLE I.—OBSERVED INTENSITIES FOR DIRECT AND INDIRECT ILLUMINATION.

Observer	Observed illumination in candle-feet.						Light brought up or down	Average indirect	Average direct	Ratio of indirect to direct
	Indirect	Direct	Indirect	Direct	Indirect	Direct				
A	1.2	1.4	1.2	1.2	0.9		—	1.1	1.3	0.85
	1.2	1.4	1.5	1.6	1.4		—	1.4	1.5	0.93
	2.4	2.1	2.4	1.8	2.4		up	2.4	2.0	1.20
	2.4	2.3	2.6	2.1	2.4		up	2.5	2.2	1.14
		1.1	1.0	1.1	1.1	0.9	—	1.0	1.1	0.91
		1.1	1.3	1.1	1.5	1.2	—	1.1	1.4	0.79
B	—	0.9	0.9	0.7	0.8	0.5	up	0.9	0.7	1.29
	—	0.9	1.1	0.9	1.5	0.9	down	1.3	0.9	1.44
	1.2	1.2	1.3	0.9	1.4		—	1.3	1.1	1.18
	1.3	0.7	1.1	0.7	1.1	0.7	up	1.2	0.7	1.71
	1.6	0.9	1.0	0.9	1.1	0.7	up	1.2	0.8	1.50
	1.6	1.4	1.7	1.4	1.9	1.9	down	1.7	1.5	1.13
	2.8	2.1	2.6	2.1	2.6		up	2.7	2.1	1.29
	2.8	2.6	2.8	2.6	2.8		down	2.8	2.6	1.08
C	1.5	1.5	1.2	1.1	1.3		up	1.3	1.3	1.00
	1.5	1.6	1.6	1.4	1.6		down	1.6	1.5	1.07
	+ 1.5	1.2	1.3	1.2	1.5		up	1.4	1.2	1.17
	+ 1.5	1.2	1.7	1.1	1.7		down	1.6	1.2	1.33
	2.4	1.6	2.4	1.7	2.0		up	2.3	1.7	1.35
	2.4	1.9	2.7	1.9	2.5		down	2.5	1.9	1.31
D	1.5	0.7	1.1	0.7	1.0		up	1.2	0.7	1.72
	1.5	0.4	1.3	0.4	1.4		up	1.4	0.4	3.50
	1.5	0.4	1.5	0.5	1.5		down	1.5	0.5	3.00
	2.4	1.6	1.6	1.6	1.6		up	1.8	1.6	1.13
	1.6	1.4	1.8	1.4	1.8		down	1.7	1.4	1.21
E	1.5	1.2	1.5	1.0	1.4		up	1.5	1.1	1.36
	1.5	1.2	1.6	1.4	1.6		down	1.6	1.3	1.23
	2.4	1.6	2.4	1.6	1.7		up	1.8	1.6	1.13
	2.4	1.9	2.6	2.1	2.6		down	2.5	2.0	1.25
F	1.5	1.2	1.4	1.4	1.3		up	1.5	1.3	1.15
	1.5	1.4	1.2	1.0	1.3		up	1.3	1.2	1.09
	1.5	1.4	1.4	1.2	1.3		down	1.4	1.3	1.08
	2.4	1.6	2.0	1.4	2.0		up	2.1	1.5	1.40
	2.4	1.6	2.4	1.6	2.0		down	2.3	1.6	1.44
G	—	1.1	1.2	1.1	0.9	1.0	—	1.1	1.1	1.00
	—	1.1	1.6	1.8	2.0	1.9	—	1.6	1.8	0.89

TABLE II.—SUMMARY OF RATIOS, INDIRECT TO DIRECT ILLUMINATION.

	For lower illumination			For higher illumination		
Observer	Light raised	Light lowered	Average	Light raised	Light lowered	Average
A	0.85	0.93	0.89	1.20	1.14	1.17
B	1.50	1.13	1.32	1.29	1.08	1.19
C	1.00	1.07	1.04	1.35	1.31	1.33
	1.17	1.33	1.25	—	—	—
D	3.50	3.00	3.25	—	—	—
E	1.36	1.23	1.30	1.13	1.25	1.19
F	1.09	1.08	1.09	1.40	1.44	1.42
G	1.00	0.89	0.95	—	—	—

DISCUSSION OF THE RESULTS.

Though, as previously mentioned, in some cases there is a more or less marked tendency for the illumination estimates to drift according to the raising or lowering of the light, there seems to be no consistent difference in the average values due to this cause. Also there seems to be no consistent difference dependent on whether the change is made from direct to indirect or from indirect to direct.

In the case of observer C, an extra set of readings were taken to determine whether the time occupied in the estimating, played any part in the results. The two series marked with + were taken slowly, the eyes being given two minutes in each case to become accustomed to the light before the final judgment was made. No definite effect was however established, though the higher ratio obtained is interesting.

In the case of five of the seven observers more candle feet are called for with the indirect than with the direct illumination. Observer A required less of the indirect light at the lower value but more at the higher.

At first sight it might seem that the greater enlargement of the pupils under indirect illumination, would give a contrary result and this doubtless would hold, if more brilliant light sources, say naked filaments, had been used within the field of vision. The relation found may be due to the more brilliant general effect produced by the direct lighting. Further investigation of this matter will be made.

It is also noticeable that while most of the observers seemed to have fairly definite ideas that more indirect than direct illu-

mination was needed, there was no agreement between different observers as to the proper ratio and in general no definite effect of the lower or higher illumination on the ratio. In some cases the ratios are not consistent for the same observer starting with the same illumination, but in considering these the conditions of the test must be kept in mind.

CONCLUSION.

1. A notable capacity for retaining a concept of an illumination value and of reconstructing it after an interval of time, is demonstrated.

2. For a given observer and a given value of illumination a rather definite preferred relation between direct and indirect illumination is found. This relation generally differs more or less from unity and in the great majority of cases indicates a demand for more indirect than direct illumination.

DISCUSSION.

S. G. Hibben: I would like to ask Prof. Caldwell how much, in his opinion, the background or wall behind that table would influence the observer, and if he could estimate the relative amounts of light on that wall from the two different lighting systems? It seems to me that that would influence the observer more than the very oblique view of a horizontal table surface at a distance equal to the diagonal of the room.

J. L. Minick: This paper should have considerable practical value in railway work and it is very desirable that the investigations of Dr. Caldwell be continued. While there may be some demand for indirect lighting in train service, the cost of furnishing such service at the present time would probably be prohibitive.

Car lighting batteries are now as large as they can be made consistent with ease of handling, etc., and the duty imposed upon them in many instances is close to their maximum capacity. If indirect lighting should be used the current consumption will be increased several hundred per cent. for the same illumination intensity and the batteries will not be able to handle the service. Furthermore if as stated in this paper "there is a tendency to demand higher intensities with indirect lighting," and I fully

agree with this statement, the demand for current will be still further increased which will prohibit the use of this class of lighting in railway service for some years to come.

M. G. LLOYD: It seems to me that we should be very careful how we apply the results obtained in experiments of this kind, because there may be a question as to what these results really mean. An observer in a test of this kind is influenced by the contrast in his field of vision and it appears that he considers the illumination higher when the source of light is in the field than when the same intensity is supplied indirectly. In the case of car lighting raised by Mr. Minick, no such contrast comes into consideration, but what is required is to give the same facility for seeing. These experiments present no evidence as to the ability to see under the two conditions, and consequently no conclusions can be drawn from them as to the relative intensities required with direct and indirect lighting equipments.

F. C. CALDWELL: In reply to Mr. Hibben; the question of how much bearing the wall has on the results is one of those which we wish to go further into. The brightness and character of the wall might well affect the decision. However, the table was rather low and the observer sat on a high stool so that he looked rather downward on to it, so it was decidedly the center of his observation.

Dr. Lloyd has really brought up the kernel of the whole matter. If the lights are entirely out of the field of vision, there should be no difference between the effect of direct illumination and indirect illumination, assuming that you have the same foot-candle illumination. The only difference can come from the fact that the light sources are in the field of vision, and that is just the point that we are undertaking to investigate. Take this room, for instance; would an observer say that the objects in this room were better lighted when he could see the lamps than he would if he had the same illumination from indirect light sources? The results obtained seem to indicate that he would; if so, it would seem to be a psychological effect; that is, he would, as it were, translate the brightness we see in the light sources on to the furniture. This would thus give an effect opposite to that produced by contraction of the pupils due to the lights in the field of vision. In the extreme case of a bright light directly in the field

of vision the contraction of the pupil is of course the dominating factor, but what is the effect on vision when the lights are less directly in view? It is a phase of this question that we are here studying.

The arrangement of the lights under test seems not to be well understood. Only one of the two sets of lighting units appear in Fig. 2, the other bar being toward the observer. Both of these bars were revolved together about pivots at their centers. Thus either the two indirect fixtures were in position for test as shown in Fig. 2, the prismatic clusters being out of the way against the wall, or, the bar being turned end for end, the prismatic clusters were brought into position.

COLORED GLASS IN ILLUMINATING ENGINEERING.*

BY HENRY PHELPS GAGE.

Synopsis: This paper considers the transmission and absorption of the spectrum through glasses of different colors. The various shades of red, yellow, green, blue, violet, together with the infra-red and ultra-violet, are dealt with. Brief mention is made of some of the processes of manufacture; the commercial practicability of the different glasses and the use to which certain colored glasses are put. A number of spectograms and curve sheets give transmission data for various wave-lengths of the spectrum.

Contrasting the use of colored glasses in illuminating engineering with the colored glasses in use for signaling, we find that in signaling highly saturated colors are required, approximating monochromatic spectral colors in purity of hue. Such glasses transmit freely some parts of the spectrum while abruptly removing all other parts. In illuminating engineering on the other hand, tinted rather than colored glasses are desired; and often the body of the glass is required to be of diffusing character, rather than transparent.

The colors made available by the glass-maker include all the colors of the spectrum, and the purples. The term colored glass may be taken in a broad sense to include, not merely absorption or transmission of ether radiation within the limits of the visible spectrum, but also to include the property of transmitting or absorbing the ultra-violet or infra-red. This "invisible" color may or may not also be accompanied by visible color.

RED.

A catalogue of the colored glasses includes three reds. Copper ruby is most often seen in the form of flashed ruby; that is, where the glass blower's iron is first dipped in the copper ruby and then in the clear or colorless glass. This results in a thin layer of the intensely colored glass welded to the inside surface of the glass bubble. Almost all of the sheet ruby on the market is

* A paper presented at the tenth annual convention of the Illuminating Engineering Society, Philadelphia, Pa., Sept. 18-20, 1916.

of this variety. The spectral characteristics of this glass in thin layers are high transmission of the red, an absorption band in the yellow green, transmission of the green, and rather complete absorption of the blue (Fig. 16). This results in a yellow or orange glass. In thicker layers a pure but dark red is obtained (Fig. 9). With copper ruby complete transmission of the red is not compatible with complete absorption of other colors.

Gold ruby is not so common as copper ruby. In thin layers, as in flashed glass, the spectrum shows an absorption band in the green, the transmission of blue and violet being moderately high (Fig. 17). This results in a purple or pink color. In thick layers it gives a pure red, but the transmission for red is not high (Fig. 20).

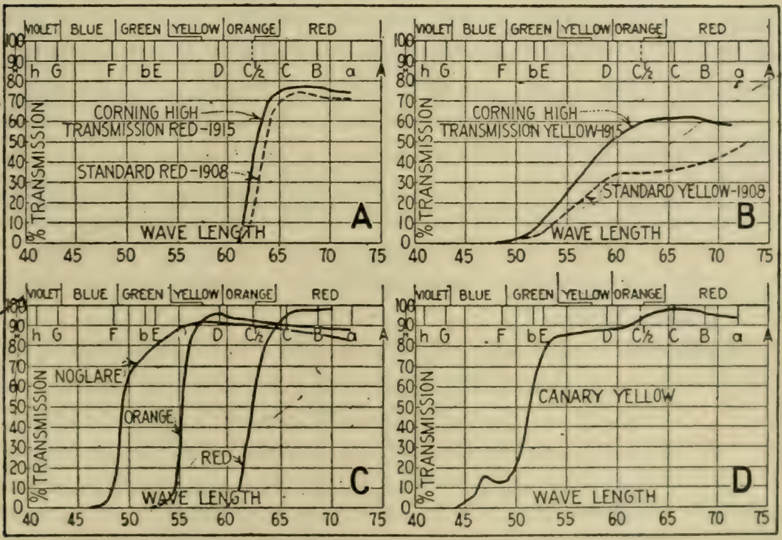

Fig. 1.—Characteristic transmission curves for colored glasses.

The purest red is known as selenium red (Fig. 1-*A*, 1-*C*, 18, 21), selenium being one of the essential coloring agents. The spectrum shows nearly complete transmission for red light (75 per cent. as against 90 per cent. for clear glass) and an abrupt and complete termination of the spectrum in the orange. When selenium red is very thin it may transmit some green also, resulting in an orange color.

All of the red glasses show the very interesting property of "coloring in," that is, if removed from the pot and rapidly cooled, they show no color or only a yellow. If re-heated the full color developes. This effect of heat treatment renders the reds more or less uncertain and good results can be obtained only after long experience.

YELLOW.

Carbon yellow (Fig. 1-*B*, 13) is most often seen in the common amber bottle of commerce. In the process of manufacturing the cheaper grades of glass "salt cake" or sodium sulphate is used and coke is employed to reduce it to the sulphide in order that it may be melted with the other ingredients. An excess of coke results in a brown or amber color instead of a clear or greenish glass. Carbon yellow is of an amber color inclined to be reddish in hue. It absorbs in suitable thickness the blue of the spectrum, transmitting the green and red. When of sufficient thickness to absorb blue, the green and red are but partially transmitted, hence a dark or muddy color results.

"High transmission" yellow (Fig. 1-*B*, 12) is a new amber which has recently been developed in the laboratories of the Corning Glass Works. With the same purity of hue this glass has a transmission for the red and green about 50 per cent. greater than the carbon yellow.

"Noviweld" (Fig. 2-*E*, 29, 30) is a new eye protective glass which removes blue and ultra-violet and transmits red, yellow and green. Infra-red is also to a large extent absorbed. The transmitted light is yellow-green in hue. Several shades are made. The lightest, shade 3, is suitable as a protection against bright sunlight, as when driving or boating. It is also suitable for working around furnaces. The darker shades are designed for oxy-acetylene welding, arc welding, etc. One feature of its manufacture is the possibility of examining a piece of any convenient thickness and predicting the proper thickness of the finished piece for any given shade. This is done by examining the test piece with a spectrophotometer, and calculating the absorption co-efficient for the sodium line. The shades are graded according to the transmission of yellow light of the wave length of the sodium line.

Silver yellow—a deep amber—suitable for flashed glass is obtained by the introduction of silver salts into the glass batch before melting.

It is difficult to differentiate the exact division points between red, orange, and lemon yellow (Fig. 1-*C*, 21-27), as all intermediate gradations occur in a series of glasses similar to the selenium red above mentioned. Two fairly well standardized members of this series are called by us, orange and noglare. The orange has a sharp cutting off of the spectrum in the middle of the green, and spectroscopically is similar to the red.

Noglare yellow (Fig. 1-*C*, 24) a light lemon yellow color—is also similar to the selenium red in very high transmission of the red, but the spectrum extends through the green and terminates abruptly at about 0.5μ and the blue is completely removed.

Canary glass (Fig. 1-*D*, 33) is a well established trade name for glass colored light lemon yellow with uranium. The spectrum is similar to noglare but the spectral cut-off is not as sharp and shows one or two bands in the blue. Under favorable conditions canary glass shows a bright green fluorescense.

GREEN.

Chromium (Fig. 2-*F*, 34) is one of the oldest and best known green coloring materials for glass. It results in a yellow green or grass green. The red and blue are both absorbed when the glass is of sufficient thickness, but the green is also absorbed to a considerable extent. In railway signal work the chrome green color is not suitable as it is easily confused with yellow.

Signal green (Fig. 2-*G*, 6, 15) or admirality green, absorbs all of the red, transmits a small amount of orange and transmits most of the green. In the blue there is again some absorption. When used with kerosene flame this glass transmits a slightly bluish green which has been found to give the best contrast with red for railway signal work.

It has recently been found possible to increase the transmission of the green without disturbing the purity of hue. This new glass is designated as high transmission admirality green (Fig. 2-*G*, 14).

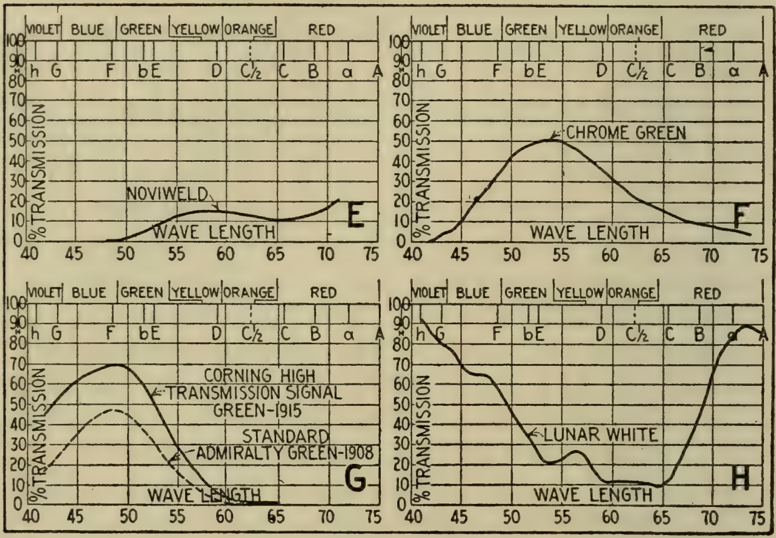

Fig. 2.—Characteristic transmission curves for colored glasses.

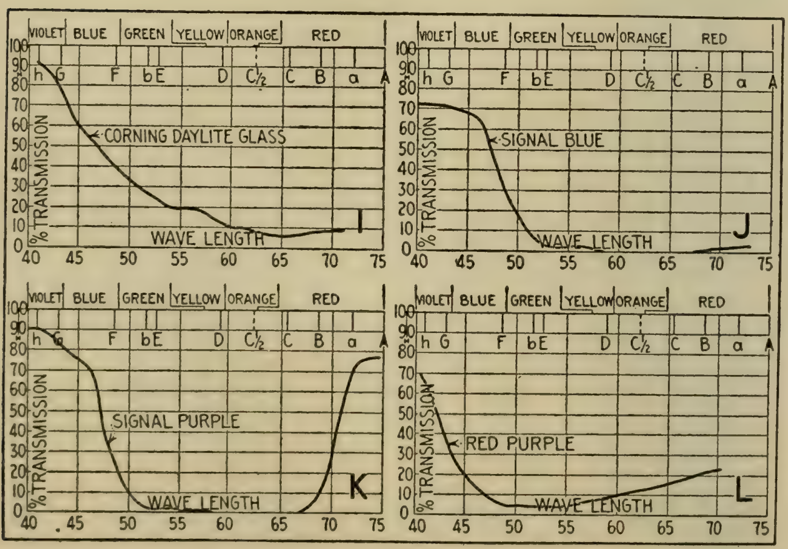

Fig. 3.—Characteristic transmission curves for colored glasses.

Blue green (Fig. 35) results from a glass absorbing red and transmitting green and blue green. Spectroscopically it is the complementary of the red, although it is impossible to get as sharp a cutting off of the spectrum as is possible with the selenium red.

BLUE.

Blue is ordinarily produced by the incorporation of cobalt in glass. The result is, however, not a pure blue, but, strictly speaking, is a purple. Cobalt glass transmits blue, and the extreme visible red, absorbing the green, yellow and orange (Fig. 31).

Lunar white (Fig. 2-*H*, 7, 38) is a light blue as seen by daylight. It is used for signal purposes to give a white light when placed in front of a yellow kerosene flame. Its spectrum shows irregularities and appears rather sharply banded.

"Daylite" glass (Fig. 3-*I*, 39) when of correct shade, appears similar to lunar white in hue, but does not have the spectral irregularities of the latter.

Signal blue (Fig. 3-*J*, 8) is a nearly pure blue without the addition of red.

PURPLE.

Signal purple (Fig. 3-*K*, 9) used in railway signals contains blue and extreme red. When used with a kerosene flame and viewed from a distance the appearance to the normal eye is that of a red disc surrounded by a blue halo. The chromatic aberration of the eye is sufficient to separate the focusing points of the red and the blue sufficiently to produce this effect.

Purples containing a large proportion of red are magenta or wine color and are designated as red purple (Fig. 3-*L*, 40, 41). The "amethyst" spectacles sometimes met with are a pale tint of this color produced by manganese.

NEUTRAL SMOKE.

Neutral smoke is useful in photometric apparatus and for spectacle purposes. There is no single coloring agent known which will give glass a neutral smoke color. The effect can be produced by combining two complementary absorptions such as green and purple, brown and blue or yellow and blue, or red and blue-green. It can readily be seen that if the two colors are not combined in the exact proportions, or if one of the coloring agents burns out more than the other, the one in excess will preponderate

and a decided color will be seen in the resulting glass. Moreover, in practically all smoke glasses, the spectrum shows a banded appearance due to coloring materials such as cobalt or nickel, or both. To obtain a perfectly neutral smoke glass with a smooth spectrum, would probably require an exhaustive research.

This completes the cycle of the spectral colors from red to blue through green and back *via* the purples.

The glasses with "invisible" color will now be described.

ULTRA-VIOLET.

In the ultra-violet, all glasses absorb more or less, the clearest "uviol" or "ultra" glasses transmit as far in the ultra violet as 0.29μ, whereas many remove all of the ultra-violet. It should be made plain that any clear colorless glass if sufficiently thin will transmit ultra-violet, and that even the best "ultra" glass, in sufficient thickness will absorb as much ultra-violet as the usual, but extremely variable standard known as "window glass."

ULTRA-VIOLET ABSORBING GLASSES.

It has been found that ultra-violet radiation is injurious to the eye, the greatest and most deep seated injury resulting from radiation about wave-length 0.280μ to 0.302μ.[1] Many ophthalmologists are of the opinion, that radiation nearer the visible, although injurious to a less extent is objectionable, and is likely to cause damage to the eye. Two colorless glasses used to protect the eye against the ultra-violet rays are the so-called "Crookes" glass and the Corning "noviol." Other glasses having strong ultra-violet absorption have also marked visible color.[2]

The "Crookes" glass on the market is of two kinds; one has a slight pink color when viewed edgewise, the other is a light neutral smoke. In a 2 millimeter layer as required for spectacle purposes, either variety removes the 0.359μ band of the carbon arc, but transmits the 0.388μ band of the carbon arc.

The Corning noviol glass (Figs. 25-27) in the lightest or "A" shade is nearly colorless, but shows a pale straw color when viewed edgewise. This glass removes all of the ultra-violet below the 0.388μ band of the carbon arc, and also removes all or most of

[1] Burge, W. E., "Ultra-Violet Radiation and the Eye," TRANS. I. E. .S, vol. X, p. 932.

[2] Luckiesh, M., "Glasses for Protecting the Eyes in Industrial Processes," TRANS. I. E. S., vol. IX, p. 472.

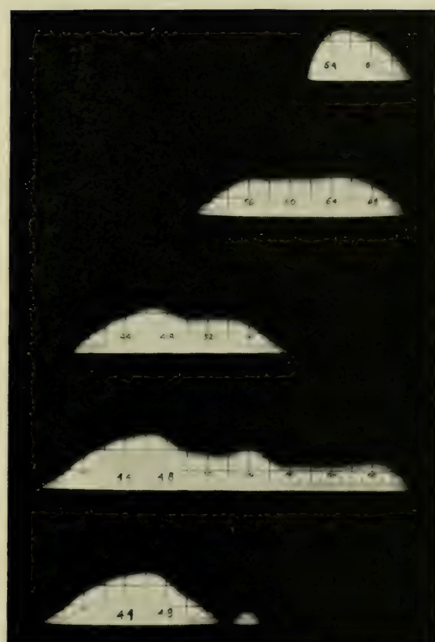

Fig. 4.
Red.

Fig. 5.
Yellow.

Fig. 6.
Green.

Fig. 7.
Lunar white.

Fig. 8.
Blue.

Figs. 4-8.—Spectograms of colored glasses used in railway signals.

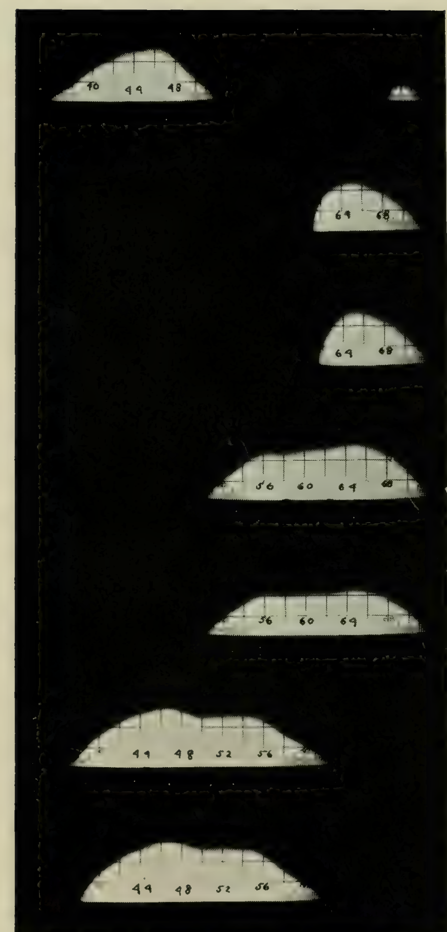

Fig. 9. Purple.

Fig. 10. High transmission red.

Fig. 11. 1908 red.

Fig. 12. High transmission yellow.

Fig. 13. 1908 yellow.

Fig. 14. High transmission green.

Fig. 15. 1908 green.

Figs. 9-15.—Spectograms of colored glasses used in railway signals.

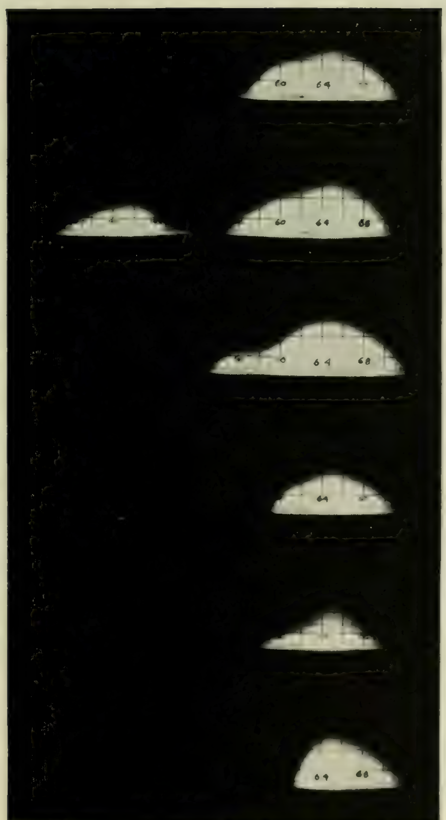

Fig. 16.
Copper ruby, thin.

Fig. 17.
Gold ruby, thin.

Fig. 18.
Selenium red, thin.

Fig. 19.
Copper red.

Fig. 20.
Gold ruby.

Fig. 21.
Selenium ruby.

Figs. 16-18.—Red glasses in thin layers showing impure spectra.
Figs. 19-21.—Red glasses in sufficiently thick layers to show pure spectra.

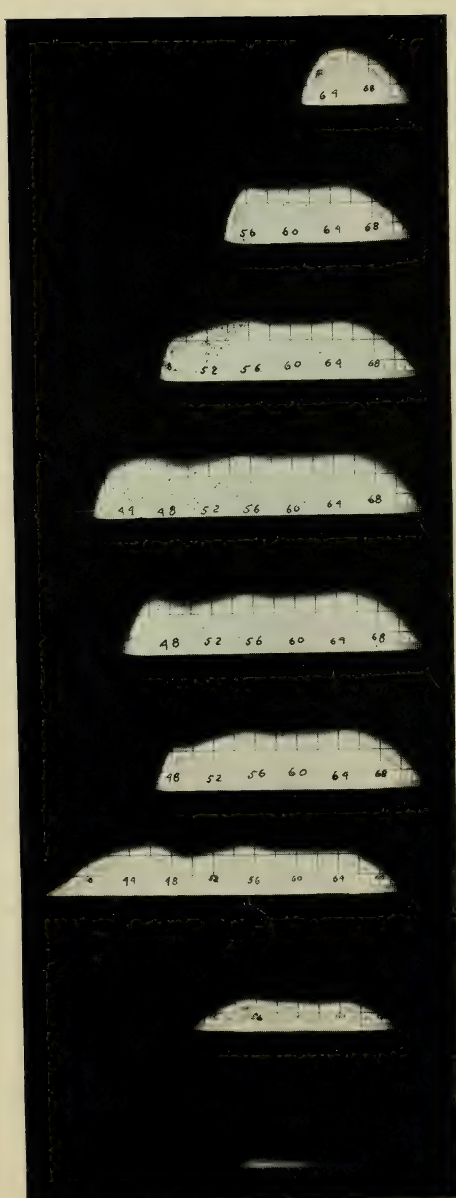

Fig. 22. Selenium red.

Fig. 23. Orange.

Fig. 24. Noglare.

Fig. 25. Noviol, shade A.

Fig. 26. Noviol, shade B.

Fig. 27. Noviol, shade C.

Fig. 28. Heat absorbing.

Fig. 29. Noviweld, shade 3.

Fig. 30. Noviweld, shade 6.

Fig. 22-27.—Colored glasses having sharp spectral termination similar to selenium red. (Compare Fig. 25, for noviol A, with Fig. 37 for sensitiveness of the plate. Note that the extreme light transmitted by the noviol shade A is wave-length 0.41, whereas the plate is sensitive to 0.36.) Figs. 28-30.—Eye protective glasses.

the 0.388μ band itself. We thus have a glass which removes all of the invisible ultra-violet and whose absorption encroaches scarcely at all on the visible violet. The darker shades of noviol are lemon-yellow in color and present the same color as noglare.

INFRA-RED.

The infra-red transmission of glasses has received considerable attention for a long time, and it is well known that for the longer wave-lengths, glass is opaque. The ordinary clear glass employed in spectacles is of considerable protection to the eye from the radiant heat of glass furnaces, etc., and in studies of optic projection it has been found that the glass of which the condensers are made removes the radiant energy in much greater proportion than the light. To still further remove the invisible radiation, water cells can be employed.

Glass can be colored in such a way as to be nearly opaque to infra-red radiation and yet transmit the greater part of the visible light. For example, a test was made of a piece of "heat absorbing" glass (Fig. 28), 2.5 millimeters thick, which transmitted 50 per cent. of the light from a high efficiency incandescent lamp and transmitted but 10 per cent. of the total radiation. The invisible infra-red is practically all absorbed. The color is a pale green. Then main use of this glass is for protective goggles where the radiant heat from a furnace such as glass furnace is very disagreeable, and where at the same time it is essential that little reduction in light intensity be allowed.

It has been proposed to use this glass in projection lanterns to protect the film or lantern slide from overheating. This purpose is easily accomplished but the protection afforded to the slide is given at the expense of heating the protecting glass.

DIFFUSING GLASSES.

To the illuminating engineer the diffusing glasses are of the greatest value, but from personal experience I can add but little to the knowledge of this important subject.

The diffusing qualities are contributed by small crystals, or in some cases spherical inhomogenieties, scattered through the clear matrix of the glass. The crystals are formed when the glass just above the melting temperature is supersaturated with respect to certain constituents. Some glasses which are ordinarily clear

become cloudy under prolonged heat treatment just below the melting temperature or on re-heating. This clouding is somewhat similar in occurrence to the "coloring in" of red glasses. In fact the "coloring in" of gold ruby has been itself ascribed to a crystallization of metallic gold from the glass body.

A glass showing this clouding on re-heating exhibits the peculiar properties of light scattered from small particles, in that the shorter light waves are scattered to a greater extent than the longer ones. The result is a blue appearance as seen from the side, and a red or yellow appearance as seen by transmitted light. This phenomenon is not a fluorescence, as no wave-lengths are reflected which are not incident upon the glass. Most opal glasses tend to exhibit this behavior with respect to transmitted light. If one of these opal glasses, however dense, is thin enough so that the filament of an incandescent lamp can be seen through it, the filament is of a red or yellow color. It has been found possible to make opal glasses which are not thus selective in diffusion and transmission.

Opal may be either solid or flashed. It may have the general properties of complete diffusion nearly following Lambert's cosine law, or it may exhibit more the properties of ground glass, transmitting a higher intensity in the direction of the incident beam than in other directions.

Opal glass may be clear or colored. Much of the decorative glassware now in use, might be described as a colored opal glass.

FLUORESCENT GLASSES.

Many glasses are fluorescent to a slight extent. This is most easily detected by exposing them to the light of the quartz mercury arc and examining them with a pocket spectroscope. A diffusing glass will show only the mercury lines, whereas, a fluorescent glass will show bands of colored light between the mercury lines, not present in the original light source.

Flint glass shows a blue fluorescence. Corning "noglare" and selenium red glass show a fair red fluorescence.

The most marked fluorescence in glass is exhibited by canary glass, *i. e.*, glass colored with uranium. Use is made of this property in certain glass reflectors. The glass of which the reflector is made is slightly colored with uranium. This coloring

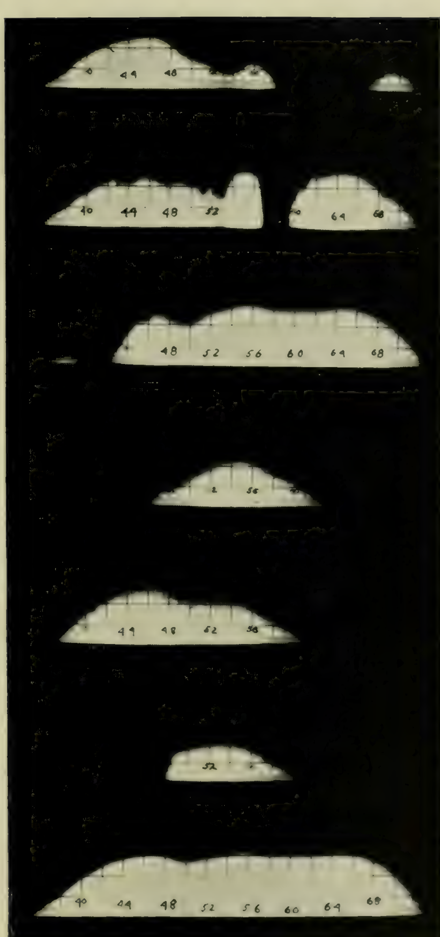

Fig. 31.
Cobalt.

Fig. 32.
Didymium.

Fig. 33.
Uranium.

Fig. 34.
Chrome green.

Fig. 35.
Blue green.

Fig. 36.
Blue green plus noglare.

Fig. 37.
Clear.

Figs. 31-33.—Colored glasses exhibiting banded spectra. Figs. 34-36.—Green glasses. (The glass illustrated in Fig. 36 is a combination of blue green and and noglare yellow, and exhibits the same shade to the eye as chrome green.) Fig. 37.—Spectogram showing the curve of sensitiveness of the plate used, *i.e.*, Cramer spectrum process.

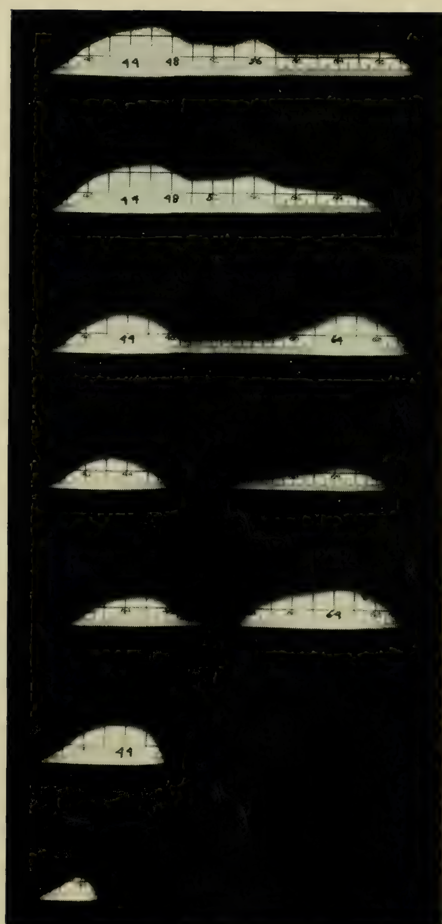

Fig. 38.
Lunar white.

Fig. 39.
Daylite.

Fig. 40.
Magenta.

Fig. 41.
Manganese.

Fig. 42.
Thin gold ruby.

Fig. 43.
Blue purple, ultra.

Fig. 44.
Red purple, ultra.

Figs. 38-39.—A comparison between lunar white and daylite glass. (Both appear by daylight, to be light blue glasses of about the same color.) Figs. 40-42.—Red purple or magenta colored glasses. Figs. 43-44.—Deep purple glasses. (These are used as color filters for isolating extreme violet and part of the ultra-violet. A band of extreme red, not shown in the figure but visible to the eye, is also transmitted by these glasses.)

is so faint that on looking through the glass, the appearance is a light straw color. When used with a highly concentrated filament incandescent lamp, the light is reflected in a parallel beam of nearly colorless light. Enough blue is however absorbed to cause the glass to fluoresce a bright green.

The amount of fluorescence in canary glass, while comparable to that of many organic substances, is surpassed by that of uranyl salts (uranium nitrate, etc.) and by anthracene (green fluorescence), rhodamine (red fluorescence) and perhaps one or two others.

USES.

The uses of color in illuminating engineering may be divided into direct decorative effects, colored illumination for aesthetic effects, and illumination for specific visual effects. The direct decorative uses are seen in the stained glass windows of churches and in the coloring of illuminating reflectors and shades. Such decoration borders on the colored enamel such as is used in china and porcelain.

Colored illumination is used in stage lighting and to produce the much desired warm tones in interior illumination. In these cases, the light from the original source is filtered through either a colored lamp bulb or through a colored enclosing globe or even reflected from a colored reflector. The illumination for specific visual effects includes protection either of the eye or the work from harmful radiations. An example of the latter is the use of a red light for photographic purposes where the plate is not sensitive to red light and the eye is. For working with panchromatic plates, a green light is used with an intensity so far below that necessary to affect the plate, that it causes no damage, but the plate may still be seen (Fig. 37).

Protection of the eye from harmful radiation may consist in removal of the ultra-violet such as is met with in experimenting with the arc lamp or in arc welding. It is, moreover, possible, although the eye was developed for use in natural daylight, that in such daylight, the radiation in the ultra-violet is harmful and that under unfavorable conditions it will cause cataract in the course of several years.

Excess of visible or luminous radiation produces discomfort to the eye, and if the eye is continuously exposed to too great illumination, injury results. Therefore, reduction of the total luminosity to the point of comfort should be resorted to in all cases where one looks directly at bright light sources. Infra-red radiation, when not accompanied by excess of ultra-violet or luminous radiation, is not generally regarded as harmful. It must, however, be recognized that such radiation is uncomfortable to workers in low temperature light sources, such as glass and steel furnaces. Anything which causes continued discomfort to the eye results in irritation of the eye-ball and cornea, derangements of circulation, drying of the cornea and other slight derangements which in the course of years must result in permanent damage. In this connection, it is interesting to note that the use of ordinary clear spectacles greatly reduces the discomfort from such light sources.

As aids to vision, monochromatic light sources have been found to give the greatest possible visual acuity. Such monochromatic light sources may be obtained with the mercury arc and a suitable glass; or the spectrum of white light may be shortened by filtering the source through a colored glass or by wearing colored spectacles. The use of noglare or orange glass reduces the length of the spectrum of white light to about one-half and one-fourth, respectively. My personal experience with monochromatic or colored lights is, however, that the increase in visual acuity is accompanied by a corresponding increase in eye fatigue. There are doubtless many people with eyes of peculiar color sensitiveness to whom monochromatic or colored light would give relief.

For visual comfort, my experience has been that the complete spectrum is the most desirable. This seems reasonable because the eyes of the human race were developed to do their work with the illumination of natural daylight, and they could be expected to work continuously with the less fatigue by daylight or by an artificial light having the same distribution of energy as the daylight spectrum.

For correct color rendering, by which I mean the same rendering of colors as obtained by natural daylight, the light must have the same distribution of energy throughout the spectrum as natural daylight and must appear the same color. Such artificial

lights are the Moore light, the arc light filtered through a checker board made of colored glasses, or the light forom the tungsten lamp filtered through suitable dyed gelatins or colored glasses. The color correcting filter to be used with the tungsten lamp re-

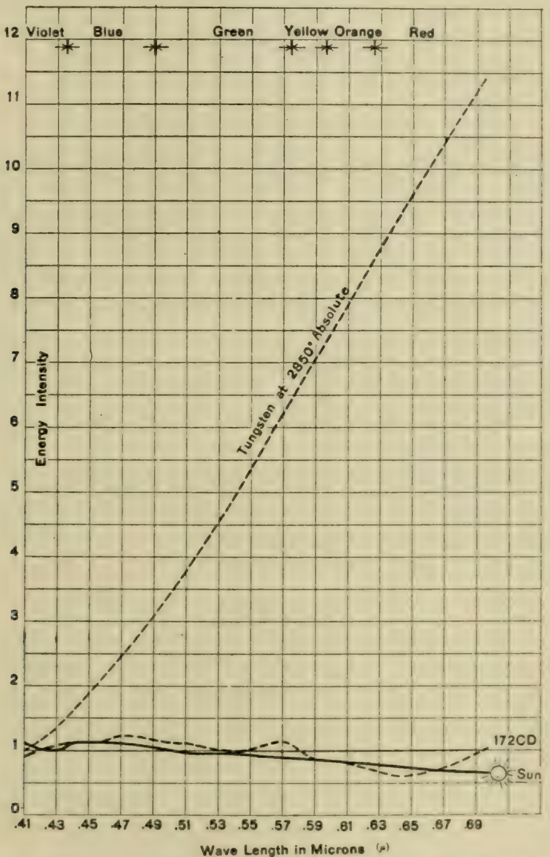

Fig. 45.—Curve of energy distribution in tungsten lamp filtered through daylight glass.

quires complete transmission of the violet and a smooth spectrum, *i. e.*, having no sudden irregularities and giving with the tungsten lamp the spectral distribution of natural daylight, as well as giving an integral or sensation white (Fig. 45).

Practical glass filters[3] have been made which transmit approxi-

[3] Gage, H. P., "Daylite Glass," *Sibley Jour. of Eng.*, vol. XXX, No. 8, May, 1916.

mately 15 per cent. of the light from the gas-filled tungsten lamp operating at 2,850 deg. absolute. This low transmission is an objection from the standpoint of the user, but is not so great as to be prohibitive, considering the high original efficiency of the new gas-filled incandescent lamps and furthermore, it is a factor which the power companies and central stations will gladly take into consideration in advocating the use of such units.

GENERAL REFERENCES.

"Ueber die Absorption des Lichtes in Farbglässem"—R. Zsigmondy, Annalen der Physik, Vol. 4 (1901), pp. 60-71. This contains spectrophotometric data on glasses of different compositions—colored with cobalt, chromium, copper, nickel, manganese and iron.

Sir William Crookes—"The Preparation of Eye-Preserving Glass for Spectacles," Philosophical Transactions of the Royal Society of London, Series A, Vol. 214, pp. 1-25 (1914).

R. C. Gibbs—"The Effect of Temperature on Fluorescence and Absorption," Physical Review, Vol. XXVIII, No. 5, May, 1909; Vol. XXX, No. 3, March, 1910, and Vol. XXXI, No. 4, October, 1910. Much of this work was done on colored glasses.

K. S. Gibson—"The Effect of Temperature on the Coefficient of Absorption of Certain Glasses of Known Composition," Physical Review, Second Series, Vol. VII, pp. 194-202.

DISCUSSION.

Clayton H. Sharp: Dr. Gage has shown us some very remarkable things in glasses, some things which I did not suspect were possible; like the production of that very sharp banded absorption spectrum. We can all see very important applications of some of these different glasses. The railway signal glass question is obviously one of very great importance. These other glass developments must also be of immediate value in other industrial lines. For example, the glass which cuts off the infrared, must be of a good deal of value to those who are dealing with industrial processes where a very high intensity of heat radiation is to be encountered. I would ask if the glasses which remove the ultra-violet so completely will be of use in spectacle work. Is it not sometimes of importance to cut off the ultra-violet which exists in daylight, particularly at high altitudes, more completely than ordinary glass does? Could acceptable spectacles be made

which would give all the visibility of clear glasses and at the same time admit none of these objectionable rays? Will not Dr. Gage give us a little better clue to the application of these glasses in the various arts which illuminating engineering touches?

M. Luckiesh: Dr. Gage's paper should be of interest to the illuminating engineer because it introduces the latter to the spectral characteristics of common glasses. I am especially interested in the spectral character and chemical content of glasses and naturally I have followed this paper with interest. I do not recognize any especially new developments from the data which have been presented. Doubtless refinements have been made in the various glasses which have been available heretofore. Many of these developments were left to foreign countries before the war but it is gratifying to note the spirit of development that has invaded our glass industries. It would be interesting to learn from Dr. Gage to what extent the colored glasses noted in the paper have been originally or independently developed in this country.

I find signal glasses convenient for obtaining color effects and many experiments in color. It would also be of interest to learn to what extent the "noglare" glass justifies its name.

F. A. Benford: I noticed in the discussion of colors in Fig. 1, that the divisions between the colors are not what I and some other people have been using. I am going to ask Dr. Gage whether they are his own determinations. For myself, I have not been satisfied with what we have accepted as the standard boundary between colors. I think perhaps his are somewhat better. Also in Fig. 1, in the lower two cuts, I notice that the transmission in three cases goes up beyond 92 or 93 per cent., which I believe is the limit for transmission through a piece of glass, on account of the 8 per cent. lost through surface reflection. Possibly these curves are simply the transmission without surface reflection being included.

S. G. Hibben: I would like to ask Dr. Gage if he cares to describe briefly and a little further the phenomena of the fringe of red seen around the purple images, in connection with the blue-purple glass. The remark he made was, briefly, that the foci of the different colors would lie at different points in front and behind the retina.

Perhaps he would also comment upon a similar phenomenon, namely, that of the fringe of orange color seen around the image of the light source when viewed through opalescent glass. At one distance this fringe is very prominent, at another it disappears.

F. C. CALDWELL: Will Dr. Gage kindly tell us about the use of colored glass for photographic dark-rooms?

L. C. PORTER: In this paper Dr. Gage says "It has been proposed to use this glass in projection lanterns to protect the film or lantern slide from overheating. This purpose is easily accomplished but the protection afforded to the slide is given at the expense of heating the protecting glass." I have experimented a little with that heat resisting glass for motion picture work and found a considerable difficulty in getting a glass which would stand the extreme temperature at the aperture place of the motion picture machine. I would like to ask what has been done to overcome that trouble? I also doubt if we can afford a loss of 50 per cent. of light absorbed by the heat-resisting glass in motion picture work; the light at best is none too strong.

HENRY PHELPS GAGE: Replying to the inquiries by Dr. Sharp as to the possible uses of some of these glasses for spectacle purposes; there has recently been considerable discussion as to whether or not ultra-violet is harmful to the eye. It is known and distinctly proved that ultra-violet of about wave-length 0.3μ is extremely harmful to the eye and has a very deadly effect. Most ordinary spectacle glass removes all light until we get in the neighborhood of 0.32μ or 0.33μ, though it might be possible that some glass would transmit the shorter wave-lengths which I have mentioned. However, while we know that the ultra-violet of wave-length 0.3μ is extremely fatal to the eye, the retina, the lens and the cornea, it may be possible that long continued exposure to the amount of ultra-violet which is met with in ordinary daylight and which is transmitted by ordinary glass, would be harmful to the eye, and working on this idea, many ophthalmologists have strongly advocated a glass which would absorb the ultra-violet almost to the visible, and to meet this requirement, the "noviol" glass was developed. The lightest shade of "noviol"

is practically colorless to the eye and absorbs all the ultra-violet. There are other glasses which do this to a greater or less extent. It is possible that in some cases it is advantageous to absorb the blue as well as the ultra-violet, and darker shades of "noviol" can be used for that purpose.

When working with an arc light, it is necessary not only to remove the ultra-violet but to reduce the visible radiation to a point called that of psychological comfort. The "noviweld" glasses were developed for this purpose, and one of the greatest difficulties was not to get the first sample but to reproduce that sample; in fact, we have never been able to do this absolutely; it is necessary to send out with the glass a prescription telling how thick it must be surfaced in order to get the particular shade required. This glass can be made of all shades, from shade 3, suitable for automobiling, boating, or where the glare of the light is too great for comfort, up to shade 13, which is useful for arc light work. This glass was also designed to cut down the infra-red as much as possible.

Regarding the uses of heat-absorbing glass, Mr. Porter has pointed out some of the difficulties when he attempted to use the glass for his particular problem. For workers around low temperature light sources, such as glass furnaces, steel furnaces, etc., the one great difficulty is that the eyes become dry and are gradually toasted. Discomfort may in time result in as serious consequences as an acute injury. For these cases we find that the heat-absorbing glass is very good. It reduces the light a little, which is an advantage. It also prevents this toasting of the eye and it is possible for the worker to see around the rest of the plant, so that he is not absolutely blinded when he looks away from the fire.

Mr. Benford had a few suggestions with regard to the curves. The division points between the colors as indicated on these curves, were taken from some data furnished by Dr. P. G. Nutting in Reprint No. 118 from the Bulletin of the Bureau of Standards, Vol. No. 6, No. 1. The spectrum may be divided into 22 divisions each of which has a just perceptible hue difference from its neighbor. Dr. Nutting calls Hue No. 1 of wave-length—420μ violet; No. 4, $\lambda = 0.463\mu$ blue; No. 11, $\lambda = 0.527\mu$ green;

No. 16, $\lambda = 0.580\mu$ yellow; No. 19, $\lambda = 0.606\mu$ orange, and No. 22, $\lambda = 0.658\mu$ red. For divisional points in the spectrum, I have adopted Hue No. 2, $\lambda = 0.435\mu$ as the division point between violet and blue; Hue No. 7, $\lambda = 0.490\mu$ as the division between blue and green; Hue No. 15, $\lambda = 0.574\mu$, as the division between green and yellow; Hue No. 18, $\lambda = 0.595\mu$ as the division between yellow and orange, and Hue No. 20, $\lambda = 0.626\mu$ as the division between orange and red. A careful examination of the spectrum will indicate that there is no very serious error involved in the choice of these division points, although of course individual differences in judgment as to their exact location would be encountered.

The spectrophotometric curves were included more as illustrations of the general shape of the transmission curves than to exhibit absolute accuracy. Some of the curves were made before our spectrophotometer was in perfect adjustment; some represent actual transmission, and some are corrected for reflection. The following curves are accurate and represent actual transmission: Curve A, red; B, yellow; G, green, H, lunar white; I, signal blue; K, signal purple. The following are corrected for reflection: E, "noviweld" and I, "daylite glass," while for the remainder, high accuracy is not claimed but they may be taken to represent corrected transmission.

With regard to the glasses used for photographic purposes—actual experience seems to indicate that a good copper ruby makes a satisfactory safe light, because if we take the very best monochromatic red which is obtainable and which is of a wave-length as far removed as possible from the blue part of the spectrum to which the ordinary plate is sensitive, and we work with a high intensity of that light, we will find that any plate is fogged, so for that reason it is necessary to work with low intensities, and the low transmission of the copper red is not particularly objectionable.

I think I can explain the reason for the separation of the red and the blue of the signal purple. Assume that a parallel beam of light made up of two beams, a red and a blue beam, strikes the eye. The refractive index of the eye is greater for blue than for red. If the red is then focused on the retina of the

eye, the blue will be focused in front of the retina and on the retina appears a blue halo. Of course if a person is far-sighted or near-sighted, there will be great differences from this appearance and this is a matter of considerable importance in the use of purple as a signal, although purple is not very important in railway signal work.

GAS AND ELECTRIC LIGHTING IN THE HOME.*

BY C. H. FRENCH AND C. J. VAN GIESON

It is the purpose of this paper to present a plan for lighting residences, which, in the opinion of the authors, should guide the engineer in planning the proper installation for the home.

If we seek primarily, the satisfaction of the customer it would seem that the lighting installation should be based upon his needs, irrespective of the department or company the engineer or salesman represents. We mean by this, that a representative of the electric department, calling upon a prospective customer, should not urge an all-electric installation and eliminate any mention as to the proper outlets for gas. The same also applies to a gas company representative, who should give due consideration to electricity.

The idea of a dual system throughout the house should be advocated and equal consideration given to both the use of gas and electricity, whether the salesman or engineer represents a gas company, electric company or a combination company.

If the idea of a dual lighting installation is put into effect, all engineers and salesmen should be instructed that they must recommend both gas and electricity and at all times, adhere strictly to this plan in their selling arguments. There is little question but that the dual service is the one which should be recommended for every home. And, if we are broad-minded enough, we can readily see that we will be doing a universal good to the people in our various communities in recommending a dual system. There is little doubt but that more gas and electricity would be used if this plan were adopted.

A great many engineers and salesmen representing either gas and electric companies, or gas and electric departments of combination companies, believe that they are doing good business if they secure a straight gas or electric installation. The electric representative is too prone to recall the fish-tail burners, used

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without reflecting or diffusing auxiliaries, and forget the rapid strides which have been made in the gas lighting field during the past few years. On the other hand, the gas company representative is very liable to present to the customer costs and lighting data based on the use of carbon filament lamps and ignore the more recent developments. This condition does really exist among the men in the field and we should not try to evade it, but instead, should take steps to eliminate this practice.

A good lighting installation can be designed equally as well for either gas or electricity, but it would be to the customer's advantage to recommend a dual installation, designed so that either gas or electricity can be used independently or one combined with the other.

Combination fixtures should not be used, as nearly all of those on the market at the present time are inartistic. The complicated arrangement of the units in most types of combination fixtures usually prevents either illuminant from performing in the most effective manner.

Where a dual system is installed and the center ceiling lighting is electricity, and the sidewall lighting gas, both the gas and electric units will be more frequently used than if there was a combination fixture in the center of the room. There are some cases, however, where the center lighting is gas and the sidewall lighting is electric, but this will not be found as universal as the first mentioned system. In houses that have been built within the last ten or fifteen years, where combination fixtures have been installed, the consumers use either gas only or electricity only. If gas is generally used, it will be found that the electric lamps are missing from the fixtures or have burned out. On the other hand, if electricity is being generally used, the gas burners will be found in such a condition that they cannot be used. This emphasizes the need of systematic inspection by both the gas and electric departments. There are a few companies, who have established maintenance departments, which make three or four inspections annually. These departments are proving of mutual benefit and satisfaction to the companies and to the consumers.

There have been cases brought to the attention of the authors, where certain fixtures had formerly been used for at least two

or three hours daily, but on which the burners or lamps had burned out or been broken, and, through the neglect of the customers to order new mantles or lamps, the burners have been out of use for many months. Naturally the consumers have gotten out of the habit of using these particular fixtures and feel, erroneously, that there is little need for them. This, of course, is a loss in consumption to the company. Where the house maintenance plan is in operation, cases of this kind are generally eliminated.

There is another reason why a dual system of lighting should be recommended; especially in suburban towns where the electric service may be interrupted through severe storms or other causes. It is well known to most of use who live in suburban districts that these interruptions, due mostly to weather conditions, have been of considerable annoyance and inconvenience to us, especially so when we were entertaining company at dinner or for the evening.

How many times we would have appreciated gas brackets in the room, which could be lighted at such times, or on occasions when more illumination is desired than could be obtained from the center fixture. By mentioning the interruptions in the electric service, we do not in any way intend it as a "knock" against the use of electricity, as most electric companies to-day are provided with, or are about to provide themselves with the best methods and means of delivering service, but we should not think them infallible. Similar objections might also be offered for the gas equipment. The point that we wish to emphasize is that dual systems should be advocated and adopted so that the customer can rely on either one of the systems in cases of accident and both can be used when required.

We have outlined, in the following paragraphs, a plan for the various rooms in the house, which we feel would give the customer every advantage and convenience.

Gas and electric outlets for the use of appliances should be considered when laying out the general lighting systems. We have, therefore, mentioned in the various rooms, not only the outlets for lighting, but those which supply any domestic appliance generally used at this time. If we, therefore, accept the policy of the dual system, it will be necessary to make a distinc-

tion between the inexpensive home and the more pretentious residence. For convenience, residences may be classed as follows:

Class "A."—Houses costing less than $4,000.00.

Class "B."—Houses costing more than $4,000.00.

Naturally, there will be variations from these classifications, and discretion must be employed in applying suggestions. At all times the general tone of the glassware and the design of the fixtures should harmonize with the decorations of the room, and the designs of the sidewall and center fixtures should be uniform in each room.

Kitchen.—Efficiency of light utilization and ease of cleaning govern the choice of the unit for this room. It is one of the rooms in the house where artistic appearance is not a determining feature. A high intensity of light is needed where food is being prepared. For the electric outlets, 60- to 100-watt tungsten lamps or inverted single-mantle gas units or small multiple-mantle gas burners are desirable. Of course, the size of the room, height of lamp above the floor, and the color of the walls have to be taken into consideration as to the candlepower of the units recommended. Prismatic glass or smooth dense opal reflectors, bowl shaped, should meet the glassware requirements for this room. Except in very small kitchens, at least two lighting outlets should be installed, at points where most of the work is to be done, such as over the sink and range. At least one baseboard outlet should be installed for the use of an electric iron. The gas iron is connected from the end of the manifold of the gas range or by a hose connection from the sidewall bracket. The best method, however, is to install a flush cover plate in the sidewall to which the gas tubing may be attached.

Living-room.—The lighting for this room should be planned with special reference to comfort and convenience. There should be a semi-indirect fixture in the center of the ceiling, and proper outlets for portable lamps and sidewall gas brackets. Gas baseboard outlets should be installed so that portable lamps or a heating stove may be used. The flush cover plate, now being generally used, is a specially designed, neat appearing gas valve,

which is installed preferably in the sidewall 3 ft. above the floor. This device merits serious consideration on the part of engineers, architects, plumbers, builders and owners of new and old houses, as it provides the best method of making portable gas connections to the sidewall rather than from tubing attached to the center fixture in the room. Where there is an open fireplace, outlet should be installed for either a fireplace heater or a gas log.

Dining-room.—The lighting in this room should consist of a center fixture of the semi-indirect type over the dining-room table and two or more sidewall gas brackets, equipped with small multiple-mantle burners. Although the semi-indirect fixture is being quite generally used, there is still a considerable demand for domes over the dining table. When the latter type of fixture is installed, care should be taken to use a bowl or shade of some type to cut out the glare from the lamp or mantle. The most pleasing effects are obtained when the glassware conforms to the color scheme of the room as nearly as possible. It is advisable to have several baseboard receptacles for fans and vacuum cleaners as well as a floor receptacle in the center of the room for the use of various electrical appliances. One or two flush-plate connections would be advisable to install so that a portable gas heater, coffee percolator or chafing dish could be conveniently attached.

Reception Hall.—A center unit is recommended here. There should also be a sidewall gas bracket equipped with multiple-mantle burner to match, in design and color, the hall decorations and the center unit. It is particularly advisable that the electric hall lights be controlled from the sidewall switch placed near the entrance door. The gas bracket should be equipped with pilot.

Upper Hall.—Combination bracket with multiple-mantle burner and a low wattage tungsten lamp with diffusing glassware should be installed here. The hall lighting should be controlled by a two-way switch so that it can be lighted either from the head of the stairs or the lower hall.

Bed-room.—A ceiling outlet in the center of the room equipped with a semi-indirect fixture, should be installed here.

In addition to this, combination brackets should be placed on each side of the dresser. It is also advisable that an electric base-board outlet be provided for a fan, heating pad or other appliances that are to be used in the bed-room. Also, a flush plate gas outlet should be installed, to which a heating stove can be attached.

Bath-room.—The lighting in the bath-room should consist of two combination brackets, one placed on each side of the mirror. Multiple-mantle burners should be used on the gas units. Gas outlets should also be provided for a heating stove and a wall type nursery burner.

Cellar.—One electric light should be installed at the foot of the stairs and one at a most convenient place in the cellar, so that light will be thrown on the furnace and coal bins. One or two gas fixtures should be installed so as to give light at the points mentioned. The electric lights should be controlled from a switch either in the kitchen or at the top of the stairs. Gas brackets should be equipped with pilot light.

In many houses, the laundry is located in the cellar, and in this event, additional outlets should be installed for the use of gas and electric appliances, such as electric irons, gas irons and laundry stove.

Porch.—The porch is becoming a very popular asset to the house the year around. There should be two outlets installed, properly placed and equipped with colored glassware. Electric ceiling units are desirable for porch lighting and should be controlled from a switch in the vestibule or hall. There are ornamental porch brackets which are very often used, one on either side of the entrance. These can be obtained both for gas and electricity.

General.—Many papers have been written on the subject of residence lighting and big strides have been made in the last few years in the improvement of both gas and electric service.

If proper thought and consideration is given to the lighting specifications and fixtures, there is no reason why every home should not be equipped to give equally good service from either.

An automobile would not be expected, month after month, to

run without cleaning and adjusting, if good results are desired. Likewise, gas and electric units should receive the same systematic attention. Glassware and metal parts of the fixtures should be kept clean and broken mantles or burned out lamps should be replaced as soon as possible.

Designing a good dual installation is becoming more difficult as time advances because of the fact that fixture and glass manufacturers, with the exception of those who are especially interested in a particular line of lighting units, seem to be gradually eliminating gas lighting apparatus. This would seem to indicate that a campaign of education along gas lighting lines should be started among fixture and glassware manufacturers.

If the plan as recommended in this paper should be adopted, its most effective use would depend upon the upkeep of the equipment. Therefore, it is essential that the lighting engineer see to it that his installations are maintained in the proper manner. No electric or gas installation will maintain itself. The lighting engineer should be as much interested in maintenance as any other department of the company, for, upon maintenance, depends the success or failure of his plan. We wish to repeat that in order to put any plan into effect, definite directions for lighting the home should be laid down by the company, somewhat in the manner designated, and all salesmen should then be required to adhere strictly to this plan in their selling arguments, whether they represent the gas or electric department.

DISCUSSION.

LEON H. SCHERCK: I look at this matter more from the standpoint of a manager of a combination company than from that of an illuminating engineer, which I do not pretend to be.

This paper is all right if you accept the premises on which it is built, but I should seriously question those premises. The author says that there is little question but that the dual service is one that should be recommended for every home, and the paper is built on the assumption that you accept this theory. Personally I do not accept it because I do not see the necessity of so doing. A dual system means not only a duplication of

wiring and piping as the case may be, but in the long run it means an increased investment for the gas or electric company for the extra mains or lines and for this duplication, naturally the public has to pay the bill. There hardly seems the necessity for the strong statement which the author makes. My experience teaches me that there is no such necessity for a dual system in the home as the author seems to think that there is. Mention is made that in case of storms in the suburban districts there are apt to be interruptions to electric service of the home. Of course interruptions do occur to electric service whether furnished from a central station or from an isolated plant, but these interruptions are not frequent. Some of the best equipped hotels in New York are those where there is only one straight system of lighting used. Hotel Astor of New York is one case which I have in mind; this hotel uses only electric lights and candles are available for an emergency. If candles are good enough in emergency for an immense business proposition like the Hotel Astor, I think they might answer in the case of the home.

Those of us who are endeavoring to advance the business, of course, always seek to eliminate waste whether this waste occurs in operating charges or fixed expenses and therefore should be alert to prevent unnecessary duplication which it seems to me the paper advocates.

Walter R. Moulton: Mr. French's paper brings to mind the special condition which exists in the city of Baltimore, description of which may be of interest.

The majority of buildings in Baltimore have been equipped with gas lighting and have gas service. Electric service is continually being installed into more and more of the old buildings, but as this work progresses gas service is not removed. The Consolidated Gas, Electric Light & Power Company aims ultimately to have both gas and electric service available in all buildings, that is, in all buildings adjacent to service mains or feeders. The company feels that the best results can be obtained by use of electric service for lighting and therefore whenever electric service is put into a building the lighting is usually changed to straight electric. A good combination fixture cannot be had, and even were such a fixture available, it is doubtful if it would be

good policy to install it at an extra expense, as the electric service is thoroughly reliable. An effort is made, however, to retain gas brackets for emergency lights and sometimes in residence work the gas fixture is retained as the ceiling fixture and electric brackets are installed.

In residence work it is not always possible to install that which is best from the illuminating engineering standpoint. The commercial necessities of the case often are the determining factor.

The interest of the consumer can best be served by giving him both gas and electric service. Gas, which is primarily a fuel, will be used for various heating appliances and for auxiliary lighting. Electricity will be used for lighting and power, as well as for a number of appliances which cannot be had with gas or which may be more convenient than gas.

J. D. LEE: Representing a gas selling organization, it is my business very often to do the best in lighting with gas that I can. In every endeavor that is made I have never found gas wanting; that is, inasmuch as anything that is necessary to be done in residence lighting, could be done with the gas fixtures available. The ceiling outlet could be equipped with a semi-indirect gas fixture or a dome or a shower, a lantern or pendant fixture. All these are to be had in endless variety.

For side-wall outlets we use brackets either with candle effects or any of the best approved designs in lighting to-day; and so I, for one have advocated all straight gas installations, and in this much do I take exception to the suggestion contained in the paper advocating a dual installation of gas and electricity.

R. B. ELY: It strikes me that we can very well get along safely and separately with either illuminant, that we can meet all needs from the illumination standpoint and illuminate both in a decorative and effective manner, both with gas and electric lighting, but on the other hand the consumers or the public generally are the final judges as to the source of lighting to be used.

A fixture, to be complete and to have the proper decorative effect, should be entirely illuminated when in use, and not have a number of sources that are dead on such fixture. For that reason, we have made it our policy, as far as possible, to give the

system that is to be used the preference in location, making it a straight fixture of either gas or electric type, and if the consumer desires an auxiliary system or emergency system, a separate and distinct system is generally advocated, keeping the two sources independent throughout the building so that both can be treated artistically and the source that is used for emergency will be made as inconspicuous as possible.

NORMAN MACBETH: It seems that combination is not the approved name for a single organization of a gas and electric company in one town, but nevertheless from the actions of the managers of many such organizations (I want to except our New Jersey friends) the combination company acts as a combination in restraint of new business.

I recall some time ago talking to a man on the subject of this paper and he said: "Do you know I believe that we ought to do more than is being done to keep our customers from constantly changing from one system to the other. It costs them money to do this and we ought to be able to furnish the right kind of a gas or electric installation and leave it in for a good many years without change."

In my opinion, it is largely a matter to be considered from the standpoint of purchase *vs.* sales. As a sales problem it may be a little more difficult to decide, but I believe that from the standpoint of purchase by the consumer, which is what the greater part of the business is to-day, this matter can safely be left in the hands of the consumer. There are a great many thousand homes that will never have anything but gas for lighting, homes that can be very much better gas lighted than they are at present. I do not believe that the combination companies are making as great an effort to take care of this business as they are to settle the question as to how they should approach the possible business in new homes. The difficulty is not one that can as easily be decided by the management as by the consumer, and depends mostly upon salesmen who know the lighting business. It is not at all difficult when on the ground to decide whether an installation should be gas or electric. I have an idea that electric service in the residence could carry a rate of 20 or 25 cents per kilowatt hour. Most central stations claim that it costs them much more than

they are now receiving for residence service, and I have no doubt that the consumer would at least be agreeable to paying the cost of service. Electric lighting has been capitalized to at least that value. In a combination company I should think the thing to do would be to find out which service, at the existing rates, pays. What is good business for the company is good business for the customer.

Mr. Scherck referred to the use of candles of which tens of thousands are still in regular use. A candle is not a cheap source of light, but has been able to justify its high price of one cent per candle hour.

The use of gas on side brackets and electric light from central fixtures is a practice which has been largely influenced by the discoloration of gas fixtures of the older type. Within the past year or two there has been considerable advancement made and much of this complaint is now out of date. Gas lamps can be secured which will not result in fixture discoloration and which may be used to advantage on central outlets.

The authors have mentioned the use of multiple mantle burners in the hallway, and I believe that this statement should be modified to "small multiple mantle burners." A multiple mantle burner has, until the past year or so, been used to describe the so-called gas arc lamp which is a combination of several standard size mantles and is comparatively a large producer of light.

T. J. Litle, Jr.: It seems to me that from the standpoint of the lighting company, no objection should be made to the dual system, because it simply means continuous illumination without interruption, and I think that a broad-minded combination company will look at it in that way, particularly since some of the larger corporations are insisting upon it in their own buildings, telephone exchange buildings, for instance, and a great many other buildings, such as halls and buildings where a large number of people congregate. As to the question of whether a candle will answer the purpose for an emergency, I should say that it would not; if you need illumination, you need something better than a candle. A candle will not furnish very good illumination for a card game; I have had that experience two or three times. It has occurred to me that it would not be very much of a hard-

ship for the combination company to furnish gas outlets in a new house, because they would at least have a gas main running through the basement for a gas range in the kitchen. Now then, as to whether or not it is necessary to have fire insurance, there may be 300 people in the room, it may be that not one of you have had a serious fire, your house has never been burned to the ground, but fire insurance is a good thing. Because you have not had a fire and have not had a personal loss, it does not follow that fire insurance is not necessary. Therefore, from the standpoint of the combination gas and electric company, I think it is a good thing to say to the consumer, "We are prepared to give you an uninterupted lighting service."

Ward Harrison: Ultimately the question of whether a consumer should install a single or dual system of lighting must be judged by the criterion "Which way does he get the most for his money?" As members of the Illuminating Engineering Society we might change this to read, "Which way does he get the best lighting for his money?" The great majority of the houses in this country are erected at an expenditure of $4,000 or less and in the case of these houses it is the unending complaint of the fixture dealer that lighting is always considered last and in fact that the fixtures, wiring and piping are all thought of in one group and the cost is pared down to a minimum. If a dual system of supply is installed it means that there is less money to be put into the fixtures and we know that upon the choice of the fixture depends very largely whether the system is good or bad. From our standpoint is it not better that the consumer should have a comfortable and pleasing light 99 per cent. of the time and no light one per cent. of the time than poor light continually?

R. L. Lloyd: This paper has been discussed from almost every point of view, I believe, except that of the home owner. I want to speak from the viewpoint of the man who builds a house and has the bills to pay and wants to provide what he considers the most convenient and necessary lighting system. To do that I would not go to the extremes mentioned either by the authors of the paper or the first gentleman who discussed it; I would strike it midway and put both gas and electric systems in

the house, but cutting one down to the minimum. Have it purely for emergency, and utilize the other to the largest extent so as to have the advantages which often accrue from a larger use. I suppose a great many gas companies offer some reduction in rates for a large consumption, the same as the electric companies do. When one tries to utilize both and have a small bill on each, he does not get any advantage from that reduction. Another reason why it would not be well to go to the limit in preparing for both, it would be an extra expense. For instance, it has been suggested that one might prepare for the use of both gas and electric irons in the laundry. What is the use of going to the expense of duplicating installation there? It does not appeal to me. There is no doubt this is an excellent paper written from the point of view of the combination company; they have got to carry water on both shoulders and make dividends for both ends of the business and the authors have done very well.

G. H. STICKNEY: One of the leading railroads when first adopting electric lighting in cars, retained gas lighting for emergencies. It later abandoned gas lighting because the equipment was neglected and it gave poor service when called on, while, on the other hand, its presence lessened the feeling of responsibility on the maintenance department, with regard to the operating system.

I believe the same condition exists, though in a lesser degree, where both gas and electric lighting is provided in houses. For example, if the electric lighting is used, the gas mantles are seldom kept up on the gas outlets. While open gas burners would, of course, avoid this objection, I still feel that personally I would prefer not to have the unused fixtures in the room, and would use candles, if necessary to provide emergency equipment.

M. LUCKIESH: It seems to me that the discussion is based upon the premise that an interruption in electric service is always fatal to the pleasure of the home circle. This is not the case because for many hours during the day an interruption would be no more serious than inconvenient. At night an interruption is more serious especially during the early hours of the evening, but even then no great or insurmountable inconvenience is suffered excepting when the interruption is coincident with an important

function. Candlesticks are always an adornment and are possible solutions of the problem arising from an interruption of service. To summarize, it appears to me to be necessary to consider the extreme rarity of a coincidence between an interruption of service and an important function that cannot be successfully taken care of by means of lighted candles. I am basing my discussion on good service conditions. If interruptions are not infrequent the solution lies elsewhere than in imposing upon each house-owner a dual system in which upkeep and preparedness is a factor not to be forgotten.

C. H. French: In a house costing $4,000, the cost of piping for gas ordinarily would be between $35.00 and $45.00. It is a very simple matter, when running sidewall outlets, to leave base-board outlets to which a portable heating stove or reading lamp may be attached. A great many people prefer to use a gas table lamp for reading. Thirty-five dollars to $45.00 added to the cost of erecting a $4,000 house is but little extra expense. And, when you consider the great convenience which may be derived for some years to come from this small outlay of money, it seems almost a crime not to have this work done.

I wish to cite here an instance where the electric service was temporarily interrupted. Some months ago, a lady was being operated on in her own home. Unfortunately, a thunderstorm came up at a critical point during the operation and the service was interrupted. Were it not for the fact that there was a gas light nearby the operating table, the physicians claim the result would have been very serious.

Proper outlets for heating units should be provided in the various rooms, not only for use in the Spring and Fall, but on occasions where the furnace is out or anyone is taken sick, during the night, it is a great convenience to be able to light a portable heater.

One gentleman made a remark that if the two systems were used in the house instead of one only, that by dividing his consumption into half electric and half gas, the consumer would lose the discount allowed on quantity consumption for electric lighting. I know of very few companies who make a reduction for electricity and gas used in the home, or, where the quantity of

current or gas used in the home very materially affects the bills, if any. In fact, most companies throughout the country do not allow any reduction on consumption for domestic purposes. However, in the case of large factories and manufacturing establishments where a large amount of power is used, gas and electric companies, in many instances, have a sliding scale rate, which is governed by the quantity of current or gas consumed. The maintenance proposition, I think, would cover the situation thoroughly, if the companies at large made semi-annual or quarterly inspections of the appliances in the home.

Again referring to the installation of gas piping throughout the house, leaving gas outlets for side-wall lighting, and outlets for the various types of appliances, I wish to state that this is really a necessity to say nothing of the convenience and comfort which may be derived from such a system.

AN APPLICATION OF PROBABILITY TO INSPECTION.*

BY W. G. HOUSKEEPER.

Synopsis: Having selected representative samples of a manufactured article, and having made careful measurements of a dimension of each sample, the paper presents a simple and quick method of calculating the per cent. of the total product which will probably lie between any two limits which may be placed upon the particular dimension under observation. A curve sheet is used, by means of which the calculations are completed. If desired, complete frequency or distribution curves may be plotted. A manufacturer is sometimes called upon to determine what proportion of his product will meet the limit requirements of a new specification. For example, it is proposed to use a part manufactured under certain standard limits in a new product requiring closer limits. It is desirable to know what per cent. of the regular product will meet the new requirements. Ordinarily, the manufacturer will take measurements of the dimension on a considerable number of parts, and then by tabulating, arrive at the desired figure. The method described in the paper was devised in an attempt to avoid the expense necessarily accompanying such a large number of measurements. The preparation for and use of the method is described in the paper, while the theoretical derivation of the method is given in an appendix.

1. We require three quantities with which to work, the total number of observations, N, the arithmetical mean of the observations, M, and the average deviation of the observations, D. With these three quantities and the chart of Fig. 1, various problems may be solved, or distribution curves plotted, as desired. The average deviation, D, may easily be calculated as follows:

* A paper presented at the tenth annual convention of the Illuminating Engineering Society, Philadelphia, Pa., Sept. 18-20, 1916.

(*a*) Add up the N individual observations and compute the arithmetical mean, M.

98.43
99.37
97.64
97.78
97.62
98.42
99.60
97.46
98.08
98.64

Sum = 983.04
Arithmetical mean, M, = 98.304

(*b*) Take the sum of all observations numerically less than the arithmetical mean.

97.64
97.78
97.62
97.46
98.08

Sum = 488.58

(*c*) Subtract the sum found in (*b*) from the product of the arithmetical mean by the number of observations summed up in (*b*).

$$5 \times 98.304 - 488.58 = 2.94.$$

(*d*) Divide twice the difference found in (*c*) by the total number, N, of observations listed in (*a*), the quotient being the average deviation, D.

$$D = (2.94 \times 2)/10 = 0.588.$$

2. Fig. 1 will be found to consist of a set of rectangular hyperbolae having ordinates, Y, at the left of the sheet, and a set of straight lines having ordinates, X, at the right of the sheet, the lines and hyperbolae having common values of D, the average deviation, as abscissae at the bottom of the sheet. The hyperbolae and straight lines are marked in per cent. There is no straight line for 0 per cent., and the 5 per cent. and 10 per cent. hyperbolae have been omitted for the sake of clearness. In the appendix will be found figures for the accurate calculation and reconstruction of this chart. The chart gives directly values of X and Y for values of D, between 1 and 10. Values of X and Y corresponding to the values of D, less than 1 or greater than 10,

can be read directly from the chart, providing the scale of X be changed in direct proportion, and the scale of Y in inverse proportion to the corresponding change in the scale of D. For example, a value of D = 0.588 was obtained by calculation in paragraph 1. It would be difficult to locate this value directly on the chart of Fig. 1. Consequently, we locate 0.588 on the

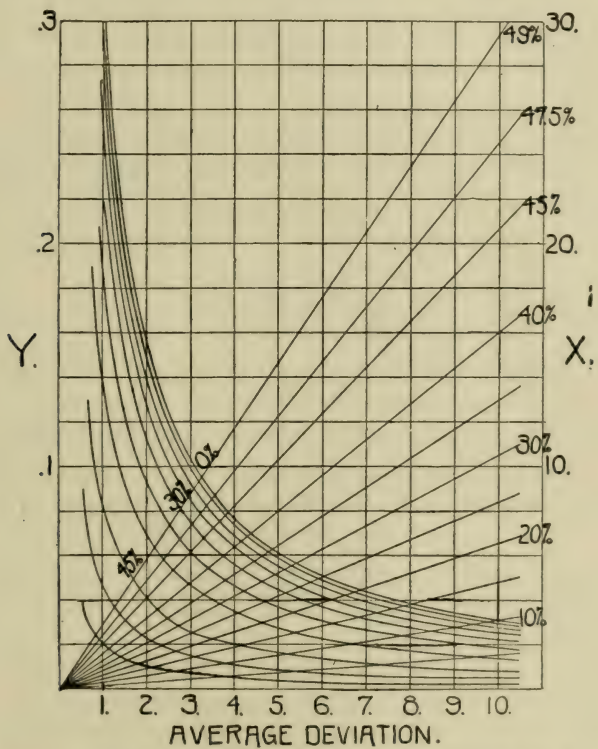


Fig. 1.—Chart used in calculation and plotting of smooth curve of Fig. 2. Abscissea are values of the average deviation, D. Ordinates to the right are amounts to be added to and subtracted from the arithmetical mean, M, of all observations in Fig. 2, to determine value of abscissea of curve of Fig. 2. Ordinates to the left, when multiplied by the total number N, of all observations of Fig. 2, give heights of ordinates of curve of Fig. 2.

chart at D = 5.88, thus dividing the scale of D by 10. The scale of X must, therefore, be changed in like proportion, the value of the divisions of X becoming 0.2 instead of 2. Thus the scale of X is changed in direct proportion to the scale of D. The scale of Y to which are plotted the hyperbolae, changes in

inverse proportion to the scale of D, thus each of the squares of scale Y for the value of D = 0.588 becomes 0.2 instead of 0.02.

3. Ordinates at the value of D (calculated as in paragraph 1) to any straight line on the chart give the variation, X, from the arithmetical mean, M, corresponding to that per cent. (by which the line is marked) of the total product contained between M and M + X or between M and M — X. This then permits of a direct solution of problems of the sort referred to in the synopsis. The following examples, using values taken from paragraph one, will illustrate more clearly the use:

Example 1: Measurements on a sample lot removed for inspection give a value of M = 98.304, and a value of D = 0.588. It is desired to calculate the limits between which 80 per cent. of the product represented by the samples will lie.

SOLUTION OF EXAMPLE 1.

(*a*) On Fig. 2, locate value of D = 0.588.

(*b*) Locate straight line = 40 per cent.

(*c*) Read corresponding value of X.

$$X = 9.45.$$

(*d*) Since scale of D is 0.1 of that shown, divide value of X by 10.

$$X = 0.945.$$

(*e*) Find values of M + X and M — X.

$$M + X = 99.25.$$
$$M - X = 97.36.$$

Hence 80 per cent. of the objects measured will lie between 97.36 and 99.25.

Example 2: In example 1, what proportion of the product represented by the sample will lie between 98.00 and 100.00? The solution of this sort of problem consists in reversing the steps used in the solution of example 1, in that the differences between the mean and the limits are first determined, which give values of X, to be located on the chart. With these values of X, and the known value of D, the per cent. of the product corresponding to the given value of X is determined by interpolation from the per cent. of the nearest straight lines. The per cent. of the product thus lying between the lower limit and the average is then added to the per cent. of the product lying between the average and the upper limit, the sum giving the total per cent. lying between the given limits.

SOLUTION OF EXAMPLE 2.

(*a*) Find difference between lower limit and average.

$$98.304 - 98.00 = 0.304.$$

(*b*) Multiply by 10 (to change to scale of X).

$$0.304 \times 10 = 3.04.$$

(*c*) Estimate value of straight line with this value of X at D = 5.88.

16 per cent.

(*d*) Find difference between upper limit and average.

$$100.00 - 98.304 = 1.696.$$

(*e*) Multiply by 10.

$$1.696 \times 10 = 16.96.$$

(*f*) Estimate value of straight line with this value of X at D = 5.88.

49 per cent. (approx.).

(*g*) Add (*c*) and (*f*).

16 per cent. + 49 per cent. = 65 per cent.

Hence 65 per cent. of the product will be found to lie between 98.00 and 100.00.

4. If measurements are made on a number of the same sort of objects, it will be found that a large proportion of the measurements center about the arithmetical mean of the measurements, there being comparatively few measurements differing greatly from the arithmetical mean.

If, now, the measurements are sorted into classes according to magnitude, then a curve may be plotted between the magnitude of the class and the number of measurements falling within each class. This will give graphically the distribution of the measurements with respect to the absolute value of the measurements. In most cases a curve will result of the form shown by broken line in Fig. 2. In this figure the broken line joins points obtained by direct observation and count. The ordinates represent number of incandescent lamps, while abscissae represent the current taken. The smooth curve is the theoretical approximation to the actual curve, obtained by calculation according to the method to be described. It is known by the various names of normal distribution curve, normal probability curve, normal frequency curve, or curve of errors.[1] It has been found to represent satisfactorily the distribution of such widely varying measurements

as incandescent lamp current at constant voltage and number of veins in beech leaves.[2]

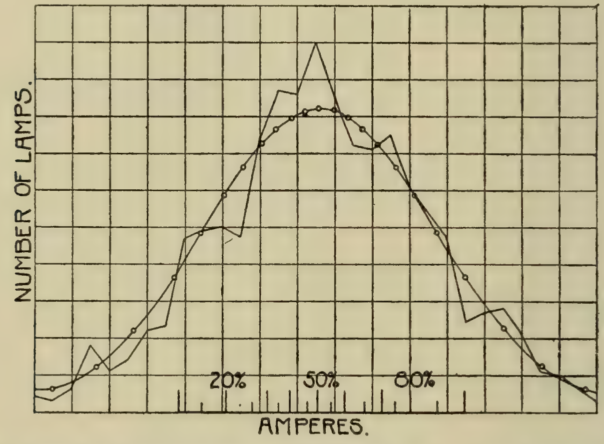


Fig. 2.—Broken curve shows observed distribution of 1,200 lamps with respect to current consumed. Irregular scale at bottom shows observed cumulative per cent. of total number of lamps. Points on smooth curve show calculated cumulative per cent.

The curve is symmetrical about the maximum ordinate which is erected at the abscissa corresponding to the arithmetical mean. Since the curve is symmetrical, except for the maximum ordinate, there are two ordinates of equal height at equal distances from the maximum ordinate. Furthermore, two distinct curves may be plotted from any given data, depending upon whether the curve is to represent per cent. distribution or actual distribution on any given number of objects. The calculation of the second curve from the first is obtained by multiplying each ordinate of the per cent. curve by the total number of objects to be represented. In plotting the curve, the straight lines and hyperbolae of Fig. 1 are used in pairs, a pair consisting of a straight line and hyperbolae marked with the same per cent. The ordinate to the hyperbolae of a pair gives the ordinate to the per cent. probability curve. This ordinate in Fig. 2 is erected at a distance from the maximum ordinate determined by the ordinate in Fig. 1 to the straight line of the pair. In other words, we read the value of X corresponding to the value of D for a straight line marked with a certain per cent. Then an ordinate y, determined by the or-

dinate at D to the hyperbolae of per cent. equal to the straight line chosen, is erected at values of abscissae equal to M + X and

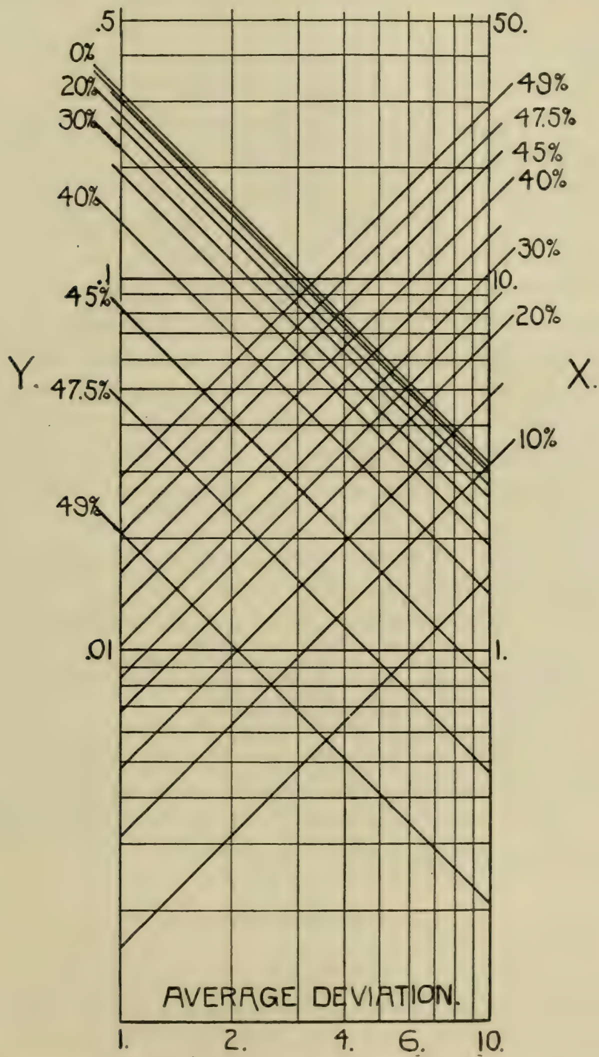


Fig. 3.—Data of Fig. 1 plotted on logarithm paper. There result two families of straight lines, the lines of one family being at right angles to the other.

M — X. Since there is no straight line for 0 per cent., the maximum ordinate determined by the 0 per cent. hyperbola is erected

at a value of abscissa equal to M. In the following table are given calculations of ordinates and abscissae of a per cent. distribution curve representing the objects of the previous illustrations.

Per cent.	y		x	
0	0.545		98.304	
5	0.537	98.212		98.396
10	0.522	98.117		98.491
15 etc.	0.501 etc.	98.020 etc.		98.588 etc.

If it is desired that the curve represent the distribution, not in per cent., but in actual number of objects, then the values of y in the above table should each be multiplied by the total number to be represented. Fig. 3 is a simplified method of plotting the data represented by Fig. 1. In Fig. 3 the data is plotted on logarithm paper, having the ordinates and abscissae spaced according to the logarithmic scale. Here the straight lines of Fig. 1 become parallel straight lines at an angle of 45 deg. with the axis of D slanting upwards to the right, while the hyperbolae of Fig. 2 become straight lines at 45 deg. with the axis of D slanting upwards to the left.

5. The normal probability curve has been found to represent observed data when:

(*a*) The measurements from which it is calculated have been made with care on the same sort of object.

(*b*) The variations from the mean of the measurements are small when compared with the mean.

(*c*) The samples selected for measurement have been selected by chance and not taken from a specially prepared lot.

Mr. Buckner Speed has collaborated with me in much of the foregoing work, and has published "A New Graphic Method of Using the Normal Probability Curve."[3]

APPENDIX.

(References are indicated by Arabic numerals; equation numbers by Roman numerals.)

The normal frequency curve is represented by the equation:

$$y = \frac{h}{\sqrt{\pi}} e^{-h^2x^2} \qquad \text{(I)}$$ [1, 2, 3]

In this equation h is a constant determining the relative shape of the curve, and e is the naperian base. When $x = 0$, y is a maximum. The curve is symmetrical about the y axis.

Equation (II) shows the relation between the constant h and the average deviation D.

$$hD = 0.5642 \qquad \text{(II)}$$ [5, 6]

Hence substituting (II) in (I), we have

$$yD = 0.3183\, e^{-\left(\frac{0.5642x}{D}\right)^2} \qquad \text{(III)}$$

In equation (III), if values of x are so chosen that as D varies, the ratio of x/D remains constant, then the simultaneous relation between y and D will be represented by the family of rectangular hyperbolae:

$$yD = 0.3183\, C \qquad \text{(IV)}$$

in which C is the constant obtained from the exponential in which the ratio of x/D is held constant. The corresponding relation between x and D will consequently be a family of straight lines passing through the origin whose slant is x/D.

In Fig. 2 the ordinates represent the number of objects at each abscissa. The sum of all the ordinates obviously equals the total number of observations, but the sum of all the ordinates to a curve, the ordinates being taken at distances equally spaced, is also the area under the curve. Consequently, the area under the broken curve in Fig. 2 represents the total number of observations, and the partial area between any two ordinates represents the number of observations between the limits represented by the abscissae to these ordinates. In the normal probability equation (I), the area between the maximum ordinate, the curve, axis of X and any other ordinate erected to the curve, of an abscissa value of hx, is represented by the integral

$$A = \int_0^{hx} y\,dx = \frac{1}{\sqrt{\pi}} \int_0^{hx} e^{-h^2x^2}\, d(hx) \qquad \text{(V)}$$

Values of this integral for various values of hx have been calculated and tabulated. From such tables, by interpolation, it is possible to calculate the values of hx, which correspond to any desired per cent. of the total area.

If, now, in equation (III) we select values of the ratio x/D so as to make the exponent in equation (III) correspond to a definite per cent. of the total area, then the values of y and x derived from their respective hyperbola and straight line will locate the

ordinate between which and the maximum ordinante that per cent. of the total area will lie. The method of this calculation, together with the actual steps in the calculation of the 10 per cent. hyperbola and straight line, are given herewith. Values of the integral (V) are ordinarily tabulated to correspond with a total area of unity for one-half the curve. Consequently, using the Smithsonian table[7], the calculation has double the numerical value of the desired per cent.

(*a*) Given the value of the fractional part of the area .... (*a*) 20 per cent.

(*b*) Determination of hx from Smithsonian table No. 23 .... (*b*)

	Per cent.
$hx = 0.18$	$A = 20.094$
$hx = 0.17$	$A = 18.999$
Difference 0.01	$dA = 1.095$

	Per cent.
Desired area =	20.000
A (for $hx = 0.17$) =	18.999
Difference =	1.001

Hence hx for A = 20 per cent. $= 0.17 + 1.001/1.095 = 0.1791$

(*c*) Calculation of x in equation (III) for $D = 1$.................... (*c*) $x = 0.1791/0.5642 = 0.3174$

This then gives the equation $x = 0.3174$ D as that of the straight line corresponding to 10 per cent.

(*d*) Value of h^2x^2...... (*d*) $hx = 0.1791 \quad h^2x^2 = 0.03208$

(*e*) Value of $e^{-h^2x^2}$ .. (*e*) $= e^{-(0.032 + 0.00008)} = e^{-0.032} \times e^{-0.00008}$

$$e^{-0.00008} = 1 - 0.00008 + \frac{0.0000000064}{2} = 0.99992$$

$e^{-0.032} = 0.9685$ (From Smithsonian Mathematical tables) (8)

$e^{-0.03208} = 0.9684$

(*f*) Value of y........ (*f*) $y = 0.3183 \times 0.9684 = 0.3082$

In like manner corresponding hyperbolae and straight lines may be calculated, the equations for which are given in the following table. The first column is the per cent. of the total area between the maximum ordinate and the ordinate under calculation. The second column is the value of the constant in the hyperbolic equation $yD = C'$, while the third column gives the value of the constants in the corresponding straight line equation $x = C''D$.

Per cent.	$yD = C'$	$x = C'' D$
0	0.3183	0
5	0.3158	0.1575
10	0.3082	0.3174
15	0.2955	0.4831
20	0.2774	0.6572
25	0.2536	0.8452
30	0.2234	1.0547
35	0.1860	1.2989
40	0.1400	1.6061
45	0.08228	2.0614
47.5	0.04683	2.4562
49	0.02050	2.9346

If desired, the various values obtained by using the curves on Fig. 1 may be obtained by slide rule calculation from the constants of the above table.

REFERENCES.

1. Edgeworth, F. X.—Probability, Encyclopedia Britannica, 11th edit., vol. 22, p. 391, par. 98.
2. Davenport, C. B.—Statistical Methods, 3d revised edit., John Wiley & Sons, N. Y., 1914, p. 12.
3. Speed, Buckner—A New Graphic Method of Using the Normal Probability Curve, Proceedings of the Casuality, Actuarial and Statistical Society of America, vol. II, part I, par. 4, 1915.
4. Mellor, J. W.—Higher Mathematics for Students of Chemistry and Physics, 3d edit., p. 516.
5. Davenport, C. B.—Statistical Methods, 3d revised edit., John Wiley & Sons, N. Y., 1914, pp. 16, 23.
6. Fisher, Arne—The Mathematical Theory of Probabilities and its Application to Frequency Curves and Statistical Methods, vol. 1, Macmillan, 1915, p. 124.
7. Smithsonian Physical Tables, 6th edit., Smithsonian Institution, 1914, table 23, p. 56.
8. Smithsonian Mathematical Tables, Hyperbolic Functions, Smithsonian Institution, 1909, table IV.

DISCUSSION.

L. J. LEWINSON: I am particularly interested in the probability curve as applied to life values, and also in respect to the number of lamps which should be life tested, although I have not attempted to use the probability curve in this particular form. We have constructed a number of spread curves, and find that

test results on a sufficient number of lamps of a well established product yield a distribution which, I imagine, will probably conform fairly well to the probability curve. We find, however, when some of the lamps perform erratically, that it is almost impossible to construct a reasonably smooth curve, particularly if we do not test very many lamps. An investigation was made

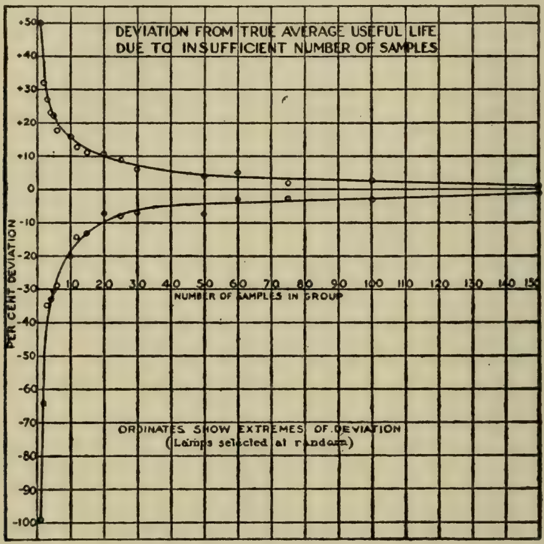


Fig. A[1].

under my direction not long ago to determine the number of lamps which should be tested in order to secure a life determination of fairly reasonable accuracy. One reason for making the study was because of frequent requests to make life tests on several different makes or types of lamps, but one or two samples of each variety being submitted. We took some 300 life values, all from the same product, and determined the average life. Next we secured two averages of 150 lamps each, taking the first, third, fifth, seventh lamp, etc., and then the second, fourth, sixth, etc. Next we took the average of every third lamp, the average of every fourth lamp, etc., thus securing three groups of 100 each, four of 75 each, and so on. The results are shown on Fig. A[1]. It appears that it is necessary to test at least 15

[1] Variables of Lamp Testing Results—Millar and Lewinson, Electrical Review and Western Electrician. Vol. 68, p. 1062, June 10, 1916.

lamps in order to get within 10 per cent. of the average of the entire 300 lamps. Of course, the results were picked at random. If we had taken all the short-life lamps and all the long-life lamps and separated them, we would have obtained greater deviations. I know that Mr. Houskeeper is interested in the life of telephone switchboard lamps, and I should like to ask him if he has ever applied the normal probability curves to life values or attempted to do anything along the line illustrated by the diagram.

WM. G. HOUSKEEPER: In answer to Mr. Lewinson's question, I have not as yet attempted to apply the probability curve to life test results. The curve seems to fit the distributions with amperes, mean horizontal candlepower, end candlepower, hot resistance and cold resistance; it does not seem to fit the watt per candle distribution. I have presented this paper with the hope that it might lead to a presentation of further papers of the sort. If, by calculation from a small number of samples, we can obtain results which otherwise could not be obtained without measurements on a great number, the saving to be realized is obvious. Biologists have done a great deal of work along this line; they are constantly tabulating and working over biological facts of the most curious sort. We, as engineers, have not done as much work along this line as might be of value to us.

DR. C. H. SHARP: I would like to ask Mr. Houskeeper whether the theory of probabilities is not based on the assumption that a sufficient number of individual observations is made to represent, through their mean, within the limits of a certain probable error which decreases with the number of observations taken, the value which would be obtained if an infinite number of observations had been made, and whether there isn't something wrong with the assumption that one can take a few samples and, by examining them, draw a correct conclusion as to what would be found if a very large number of samples were observed? I don't understand, in other words, how it is possible by any mathematical jugglery whatever, to get over the necessity of examining a large number of samples if a correct representation of the total product is desired. How does Mr. Houskeeper reach the conclusion that, by taking a small number of samples, he can get a correct idea of what he would get by an examination of a much larger number of samples? I wish he would elucidate that

a little further. I would ask him another question. In finding the mean deviation on page 1084 he gets the sum of the observations, which are numerically less than the arithmetical means. Why doesn't he simply divide that by the number of those observations, five, take the difference between the quotient and the arithmetical mean, which gives answer 0.588, without going through the additional operations, *c* and *d?*

WM. G. HOUSKEEPER: In answer to Mr. Sharp's first question—you cannot assume that your calculations on a small number of objects represent the large number until you have actually measured the large number and find that for succeeding samples your calculation will hold. When you have tested you large number of lamps, you perform your calculation and if you find that the curve does fit the result of those lamps in just the same manner as you find and use your forced test factor, you can apply this method in the same way to succeeding lamps of the same kind of construction. As to the calculation of the deviation in this particular example, it would be perfectly right to take that difference and divide it by five without the following steps. However, if you have a great number of observations, for example 50 or 60, you will find if you have to instruct an ordinary adding machine operator, that the rule given here will work out somewhat simpler in practice than the method suggested by Mr. Sharp. The point to be borne in mind is that the divisor in the determination of the average deviation is not the number of observations greater than the mean, but either half the total number of observations or the total number of observations, depending upon whether you take the sum or twice the sum of the negative deviations.

PROJECTION ENGINEERING.*

BY R. B. CHILLAS, JR.

Synopsis: This paper deals with certain requirements for the light source, in order to produce a steady picture on the screen of an intensity restful to the eye and yet great enough to give clear detail. The characteristics of the alternating-current and direct-current arcs are analyzed. Light distribution within the lantern and through the lens is discussed. The paper closes with several suggestions for improvement in the optical arrangements of the lantern.

When we consider that the business of the "Movies" in its various ramifications is now one of our leading industries, it is rather disconcerting to our pride as illuminating engineers to consider the way in which we have neglected to apply many of the principles to which we give such careful attention in other lines.

It is possible that because of the predominance of the amusement feature of this industry, many of us are inclined to be rather skeptical as to its economic value. But because of the pace at which we are driving ourselves in this age, we are demanding that our amusement and relaxation shall be similarly intensive. As a means for furnishing the most of keen enjoyment and relaxation to the greatest number of people of all ages and conditions, irrespective of race or creed, at a minimum cost per individual, the motion picture certainly occupies a position of real economic importance. It well deserves far more careful engineering consideration than has in the past been accorded to it.

This paper concerns itself directly with some of the features of the production of the light and its projection through the film onto the screen.

Requirements.—The requirements for the light source for motion picture work are that it shall be steady, of maximum intrinsic brightness and of such distribution characteristics as will permit a high degree of concentration upon the film at the

* A paper presented at the tenth annual convention of the Illuminating Engineering Society, Philadelphia, Pa., Sept. 18-20, 1916.

aperture plate. It will be taken for granted that since the motion picture field is by far the largest and the most exacting in its requirements a source which is adapted to this work will certainly be adequate for the other minor fields. The resources available to the illuminating engineer to-day are all in what may be properly classed as incandescent radiators, namely the high amperage concentrated filament tungsten lamp and the alternating-current and direct-current plain carbon arcs.[1] As yet, none of the gaseous radiators have been made sufficiently concentrated to be useful to any considerable extent.

Characteristics of Direct-Current Arcs.—In the direct-current arc the positive crater is of relatively large area and forms the principal light source. The negative crater or spot is very small and need not be considered as a light source, although the characteristics of the negative are of the greatest importance in securing steadiness of operation. It is desirable in operating such an arc to have the positive crater as nearly as possible directly facing the axis of the optical system. To secure such an arrangement with the minimum amount of shading of this crater by the negative carbon should be the aim of every operator. The principal characteristics inherent to the direct-current arc which work to its advantage as compared with the alternating-current arc are (1) that the arc is longer, giving less shading of the crater; (2) that the positive crater receives energy continuously and so maintains a higher temperature and gives a whiter light than the alternating-current arc; (3) that the net efficiency is higher as a result of the two previous characteristics.

So much of the success of arc projection depends on the proper choice of the correct size and quality of carbons that it would be well to go into considerable detail on this subject. The size of the positive crater is determined by the power input to the arc. The positive carbon must be chosen of a size such that when the arc has been established and has burned long enough to reach steady conditions, the area of the positive crater will very nearly occupy the entire end of this carbon. If the carbon is too small for the current used, the crater will overlap the end of the carbon and a condition of marked unsteadiness is bound to occur. If too large, the crater will not cover the end of the

[1] See "The Projecting Lantern" by J. B. Taylor I. E. S., May 1, 1916, p. 414.

carbon, the average temperature of the tip is low, the arc wanders and the efficiency becomes less. The size of the negative carbon required by the negative spot is very small, that is, the actual size of the negative spot for a current of 100 amperes is less than 1½ mm. in diameter compared with 16 to 18 mm. for the positive crater. It will be seen from this then that conditions other than the size of the spot determine the proper size of the negative. The principal one of these is the current carrying capacity. Any method which will increase this means that a smaller carbon can be used. In turn this results in the decided advantage that the negative spot is then confined to a very small area at the tip and increased steadiness is secured.

When a plain carbon is used as a negative, the amount of energy available is too small to maintain a well-pointed tip, provided the carbon is of sufficient diameter to carry the current. To overcome this difficulty it has been found possible to increase the current carrying capacity by a metallic coating on the carbon and correspondingly to decrease its cross section. This is perhaps the most decided improvement which has been made recently in carbons for projection work.

Characteristics of Alternating-Current Arcs.—For the sake of clearness, we can say that there are two types of alternating-current arcs in use. In the low current arcs used for stereopticon work the arc length is kept quite long and the operation is nearly noiseless except for the slight hum. From what has just been said about the direct-current arc, it will be seen that there is a large difference in the relative areas of the two craters. Consequently, with the rapid reversals of the current the function of the two carbons must alternate. This demands then a compromise on the grade of carbons to secure the best set of conditions, as it does not necessarily follow that a good positive makes a good negative. With the long arc operation there are no sharply defined craters and because of the fact that the high temperature positive spot alternates, the average temperature of each carbon tip is much lower than the temperature of the positive crater. This is the principal reason for the marked difference in efficiency of the alternating-current arc as compared with the direct-current arc.

In practically all motion picture work on alternating current,

the carbons are operated with a very short hissing arc. In fact, they are separated by the smallest possible air gap consistent with a reasonable degree of crater exposure towards the lens. Under these conditions of operation, sharply defined craters are formed, yet the average crater temperature and efficiency is much less than that of the direct current positive.

The following comparison between direct-current and alternating-current arcs at equal power consumptions in the arc may prove interesting:

Length of throw, screen to aperture plate....67 ft. (20.4 m.)
Focal length, first condenser lens.............5.5 in. (14 cm.)
Lens diameter, effective ....4.25 in. (10.8 cm.)
Screen size..........7 ft. 3 in. by 9 ft. 10 in. (2.2 by 3.0 m.)

	D. C.	A. C.
Upper carbon	16 mm. cored	16 mm. cored
Lower carbon	8 mm. coated	16 mm. cored
Current	40 amperes	65 amperes
Arc volts	54 volts	35 volts
Arc Powerfactor	—	92 per cent.
Arc watts	2,160 watts	2,150 watts
Illum. on screen	11.85 foot-candles	5.10 foot-candles

The arc position in the lamp house was the same in each case. No change was made in the focusing of the objective lenses.

The choice of the proper size of carbons for alternating-current service is governed by the current carrying capacity and the formation of the craters at the tip. With carbons of good quality, it is found that the size needed to give the necessary crater area at a given current has carrying capacity for a slightly greater current. It would not, therefore, pay to use a metal coating.

Table of Sizes.—The table below gives the sizes of carbons and the currents at which they should be operated:

TABLE I.—Size of Carbons.

For Stereopticon Work.

(Alternating-Current or Direct-Current Service.)

Current amperes	Carbons cored, mm.
4	6
6	7
10	10
15	11
20–25	13

For Motion Picture Work.

Current Amperes	Alternating current Both carbons cored, mm.	Direct current Upper positive cored, mm.	Direct current Lower negative solid mm.
40	13	16	13
45	—	16	14
50	14	—	—
55	—	19	16
60	16	—	—
70	—	22	19
80	19	—	—
100	22	—	—

For Direct-Current Motion Picture Work.
(Small Metal-Coated Negatives.)

Current amperes	Positive cored mm.	Negative solid coated, mm.
40	16	8
40–52	19	9
52–65	22	10
65–80	22–25	11
80–110	25	13

Light Distribution.—With all of the present schemes of operation, there is a great deal of light lost within the lamp housing. The distribution of light from an unobstructed circular disc radiator is represented by a sphere, with the diameter, normal to the disc, indicating the maximum intensity. The positive crater of the direct-current arc and both craters of the alternating-current arc are of this type. The best theoretical condition, therefore, would be to have the positive crater on the optical axis and directly facing the first condensing lens, and the negative carbon so placed that no shadow will be formed on the lens. Under present practice this setting is almost never used. The extent to which it is approached is a measure of the efficiency of the scheme.

On alternating current, it is necessary to depart considerably from such a setting. It has been shown that it is necessary to operate with a short arc in order to secure craters. The two craters then naturally tend to face each other and because of this almost to obscure each other. The inherent efficiency is therefore low. By carefully regulating the relative positions of the two carbons, the craters can be forced to open out a little, but the best that can be done is still far below the possibility of

direct-current work. Furthermore, it is necessary to use the light from only one crater of the alternating-current arc in order to secure sharp definition of the projected picture. The resultant

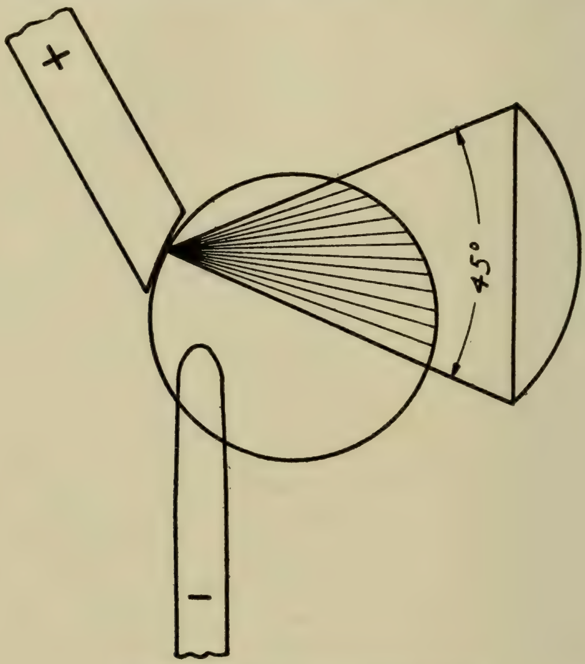


Fig. 1.—Direct-current distribution curve.

distribution of light from the best alternating-current arc is, therefore, a section derived from the spherical distribution curve of one crater diminished by the shadow of the other carbon and by the fact that the crater is inclined to the optical axis.

Compare the alternating-current and direct-current curves, Fig. 1 and Fig. 2. The direct-current maximum intensity may and often does fall onto the lens. The alternating-current maximum is never realized as it falls on the tip of the other carbon.

Utilization of Light.—The quantity of light utilized by the present lens system is measured by that which falls within the solid angle subtended by the first condensing lens. The size of this solid angle depends upon the diameter of the lens and upon the distance from the lens to the arc. The size of the lens is governed by the accuracy with which lenses of large size can be

made at a reasonable expense. This appears at present to be about 4½ to 5 in. The distance from the arc to the lens should be as small as possible, but this is limited by the amount of heat which the lens will stand. This distance with high powered arcs is about 5 in. The limit of the solid angle, therefore, is about 45°. For the best results with the present scheme it is essential that one pay particular attention to the focal length of the condenser lens. As an example, a lens of 5.5 in. focal length

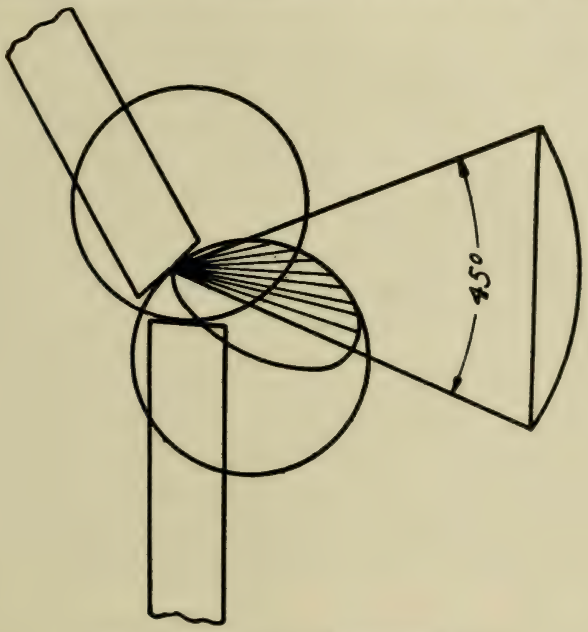


Fig. 2.—Alternating-current distribution curve.

receives 35 per cent. more light from a crater directly facing the lens, than one of 6.5 in. focal length.

On the basis of the total flux of light emitted from an unshaded circular disc source, such as a positive crater, Table II gives the maximum percentages which fall within the given solid angle, symmetrical about the axis of the radiators.

It will be seen from the above table and from the figures shown above that the maximum efficiency of a lens embracing a solid angle of 50° is only 17 per cent. In order to increase this it is necessary either to use a lens of larger diameter or else a lens

TABLE II.—PERCENTAGE OF TOTAL FLUX WITHIN GIVEN SOLID ANGLE.

Solid angle (degrees)	Per cent. flux
0	0.0
20	3.0
40	11.7
50	17.0
60	25.0
80	41.3
100	58.7
120	75.0
140	88.2
160	96.8
180	100.0

of the meniscus type, since the lens is already placed as close to the arc as it will stand. The cost of such a short focus lens or system of lenses of the necessary degree of accuracy is out of proportion to the gain secured thereby. Furthermore, the fact that the crater does not ordinarily directly face the lens and that the negative carbon frequently causes some shading, renders it highly probable that the percentage of the light which falls on the first condenser is only 10 to 12 per cent. of that produced by the direct-current positive crater. In the case of the alternating-current arc the percentage is even more pitifully small. And this does not tell the whole story, since no deduction has been made for the light necessarily cut off by the edges of the aperture plate in order to secure a fairly uniform illumination over the area of the film. The writer has not measured the light received on the screen as compared with that produced under good conditions by the arc, but ventures the opinion that it is not over 5 to 8 per cent.[1]

Possibilities of Improvement.—Every one will grant that it is desirable to secure an improvement over these conditions. To the writer, it appears that the obvious point of attack is at the arc and condensing system, to see whether it is possible to secure a scheme which permits a greater utilization of the light than the 17 per cent. secured by the present lens system.

In the optical system of the searchlight projector, the arrangement of the parabolic mirror, embracing the usual solid angle of 120° about the focus, with the positive crater at the focus and directly facing the mirror has a possible efficiency of utilization of 75 per cent. of the total flux. This assumes no shading by the negative. In other words the searchlight scheme is funda-

[1] Later measurements show this to be as low as 1 per cent. in many cases.

mentally over 400 per cent. better than the present projector arrangement. Even with the losses in light due to the shading of part of the mirror by the negative carbon, the actual percentage of the light which falls upon the mirror is about 60 per cent. of the total flux produced, or about 350 per cent. better than the theoretical possibilities of the projector.

Can a similar scheme be applied to the moving picture projector? We believe that it can. Of course, it is not practicable to apply this scheme directly, since the searchlight beam is essentially a cylinder of the diameter of the mirror so that it would require a film big enough to cover the beam, or else a lens as large as the mirror to focus the light on the film.

A scheme which to the writer appears to possess very decidedly advantageous possibilities, is in the use of an ellipsoidal mirror in place of the parabolic mirror used in searchlights. Sigmund Schuckert has a Swiss patent dated 1889, in which is shown a sketch of such a mirror with the carbons arranged as in a searchlight, that is, with the positive carbon on the axis, with its crater at the focus nearest the mirror.

An ellipsoidal mirror, generated by the rotation of an arc of the ellipse about its major axis, subtending a solid angle of 120° or 150° about the focus adjacent to the mirror and converging the reflected rays upon the other focus at an angle sufficiently small to be within the satisfactory working limits of an objective lens should offer no serious difficulties in construction and would permit a vast improvement in the utilization of the light from the arc.

The writer has calculated several such mirrors and finds that the curvature and size are by no means excessive. From the table given above, it will be seen that a 120° mirror has a theoretical possibility of 75 per cent. of the light from the crater. Compare this with the 17 per cent. obtainable with the present lenses. Even with only a 25 per cent. utilization of the scheme, it is still better than the lens scheme at 100 per cent. efficiency. A free discussion of this subject would be gladly welcomed.

The best arrangement of carbons for this would be with a horizontal positive and a small metal-coated negative carbon, inclined at about 20° to 30° from the axis. The lamp parts should be made of minimum cross section normal to the reflected rays.

DISCUSSION.

F. A. BENFORD: Mr. Chillas has mentioned the ellipsoidal mirror in his paper. Several years ago Mr. L. C. Porter submitted a similar scheme to the laboratory for test. The nickel-plated, spun-metal reflector, which was intended for stereopticon use, had a semi-major axis of 8.6 in. (21.8 cm.) and a semi-minor axis of 5 in. (12.7 cm.). The arrangement of lamp, mirror and lenses is shown in Fig. 1. The lamp had practically uniform intensity in all directions, and when placed in the usual position directly behind the condensing lens the latter collected only 9 per cent. of the total radiated light. The ellipsoidal mirror which included an arc of 289 deg. about the lamp, collected 90 per cent. of the light and, neglecting losses, reflected it to the conjugate focus at the condenser. There is here an apparent gain

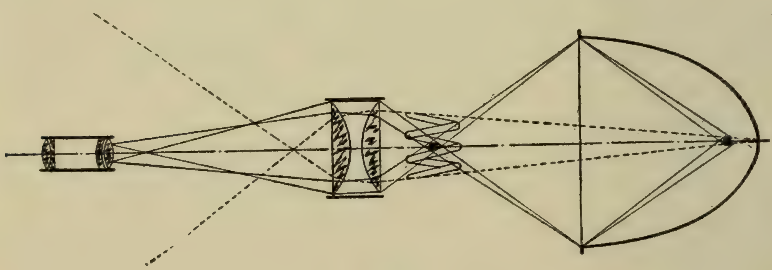


Fig. A.

of ten to one in the light reaching the curtain. The gain is apparent and not real on account of the enlargement of the images formed at the conjugate focus. Light reflected from near the edge of the reflector formed an image the same size as the filament and all of this light passed through the slide and reached the objective lens. The image formed by light reflected from the center of the reflector was enlarged many times and while the light from this image reached the condenser, after passing through the slide the spread was so great (see dotted lines on Fig. A) that only a very small proportion entered the objective. The effectiveness of this mirror in getting light to the objective then ranged from 100 per cent. near the edge to practically zero at the center. It was found that the net efficiency of the mirror was only 7 per cent. in place of the theoretical 90 per cent. based

on the assumption that all the light collected by the mirror would be effective on the screen. The over-all efficiency could have been considerably increased by using a larger (and more expensive) objective, as most of the lost light passed outside of the latter lens.

There is a further objection to the ellipsoidal mirror on account of the streaked and uneven illumination of the screen, and the dark spot due to the opening for the lamp base in the rear of the mirror.

L. C. PORTER: The motion picture machine and the searchlamp, either the large searchlamp or the automobile headlamp, are in very common use, but there is a surprising scarcity of literature on the theoretical, scientific design of these common implements, and I think the Society is fortunate in having these two very valuable papers for their TRANSACTIONS. There are other than the theoretical things to consider. We must take into account some of the practical applications and some of the practical occurrences in the application of theory to these machines. For instance, Mr. Orange in speaking of the searchlamp says, "As an example, with a given size of mirror the range with a special tungsten source is about one half of that with the direct current arc, assuming clear conditions; it is better than one half according as the atmosphere is hazy." I presume that is figured out theoretically. As a matter of fact, quite a number of tests have been made by independent parties, notable the Southern Pacific Railroad and the Pennsylvania Railroad, in connection with headlamps, in which it has been shown that objects can be picked up a considerably greater distance with an incandescent lamp source giving a lower beam candlepower than can be done with an arc lamp source.[1] I have also witnessed some more or less interesting tests in a motion picture theatre in which one reel of film was shown with an incandescent lamp as a light source and then followed by a reel with an arc lamp; the screen illumination in the latter case being nearly double the former; but several people not technically trained along that line were asked if they noticed any difference in the pictures and said that, if anything, the one shown with the incandescent lamp was more pleasing. There seems to be then something which favors the in-

[1] I. E. S. Transactions, vol. IX, No. 9, 1914, pg. 917.

candescent lamp. It may be steadiness, it may be color, it probably is both, but it should be taken into consideration in projection problems. In regard to the type of screen, we have been experimenting a little with a special type of paint which is being used in the interior of integrating spheres, and we find that this gives a very much better surface for motion picture screens than even alabastine, which is being advocated by the motion picture companies. Alabastine looks almost yellow compared to this special type of paint, and I hope that sooner or later arrangements can be made so that the motion picture people can use this paint for screen surfaces.

PRESTON R. BASSETT: Mr. Chillas has given some rather low figures on the efficiency of the ordinary moving picture optical system, and I have an interesting verification from figures obtained at the Strand Theatre in New York, which has the reputation of having very high-class projection. The Strand Theatre operates with a direct current arc of about 75 amperes. Starting, we will say, with the amount of illumination which they can get from the positive crater of that arc which figures 66,000 lumens, only about 6,000 lumens of the 66,000 fall on the condenser; that is, about 9 per cent. is utilized. Of this amount only about 3,000 lumens, or one half of what falls on the condenser, falls on the film itself, and just about one half of that falls on the screen, so that the efficiency of the amount of light that is obtained on the screen is about 2.8 per cent. of the lumens that we start with at the arc. Now the Strand Company would like more light. On the other hand, they are not kicking at all at their electric light bills; they could afford to run more amperes in their arc, as that is really a minor consideration. The thing is that they want a reliable arc, and for reliability they can actually afford to sacrifice over 50 per cent. of the available light. The way they obtain their reliability is by burning practically a vertical arc. A horizontal arc with the positive crater facing the lantern system would, of course, give a considerably higher efficiency. With the vertical arc, on the other hand, the top part of the condenser was receiving only about 5,000 candlepower out of a possible 21,000 candlepower; in other words, they only obtain about a 10 deg. view across the crater at the top part of the condenser. As Mr. Chillas said, sometimes the light es-

capes the top part of the condenser entirely. The conditions I saw were actually running conditions such as is used during every show. Mr. Chillas' suggestion of the optical system using a reflector, of course has advantages theoretically, due to the very much greater amount of light that can be utilized; but the question there comes up right away that the operator wants reliability and can actually sacrifice amperes for reliability. If the horizontal arc could be made as reliable as the vertical arc, a great deal could be said for the reflector system, I should think. I know of one case where the reflector system was used, such as has been mentioned, with a light at one focus and the screen, or rather the picture, at the other focus. This was at the World's Exposition in Chicago. They had a 44-in. reflector and about a 70 or 80-ampere arc, and threw pictures and advertisements upon the clouds with the apparatus. The results were very satisfactory and enough illumination was obtained on the clouds to read distinctly any words which were projected. This itself shows that the efficiency is very much greater than with the condenser system, since they had practically the same amount of light available that the Strand Theatre has, yet I am pretty sure the Strand outfit could not do a stunt of that sort.

A. B. Halvorsen: Was that with a metal reflector, or glass?

Preston R. Bassett: The reflector used was a glass mangin mirror which utilized about 60 per cent. of the lumens from the positive crater, as compared with the 9 per cent. utilized by the condenser system. The intense heat at the focus of the mangin mirror made it necessary to use brass stencils instead of photographic plates for the pictures which were projected. This apparatus was designed and successfully operated by Mr. Elmer A. Sperry of Brooklyn.

R. B. Chillas: With the positive crater, at the focus adjacent to the mirror, regarded as a surface source the light on the film at the aperture plate can be regarded as emerging from the mirror at a dispension angle equal to that subtended at the mirror surface by the bright spot of the positive crater.

The more divergent rays from any mirror element will probably be lost at the edges of the aperture plate, just as are similar rays from the present condenser lenses. With properly operated arc, the crater will be small, the dispersion angle will, therefore,

be small and the percentage of useful light will, therefore, be higher than with the lens condenser.

As to the relative steadiness of vertical and horizontal arcs, the latter are generally conceded to be less steady, but when such an arc can be operated throughout the life of the carbons, two or three hours without an outage, we can consider that as being quite satisfactory.

SOME EXPERIMENTS ON THE EYE WITH PENDANT REFLECTORS OF DIFFERENT DENSITIES.*

BY C. E. FERREE AND G. RAND.

Synopsis: In the work of previous papers the gradation of surface brightness and its distribution in the field of vision were shown to be important factors in the effect of lighting conditions on the eye. In the work of the last paper gradation of surface brightness was made the chief variable. Inverted reflectors of six different degrees of density were employed and a correlation was made between the illuminating effects obtained and the tendency to cause loss of power to sustain clear seeing and to produce ocular discomfort. In the work of the present paper these reflectors, with one omission because of close similarity to another in the series, were installed pendant. To these were added six types of opaque reflector differing in lining, dimensions, and design; and one of prismatic glassware. Owing to limited space the presentation of the results for the opaque reflectors has been deferred until a later paper.

INTRODUCTION.

This paper is the fifth in a series in which the effect of different conditions of lighting on the eye is investigated. In the first paper, two tests were described—one designed to be used as a general test for detecting the comparative tendencies of different lighting conditions to cause a loss in the eye's power to sustain clear seeing for a period of work; the other for detecting the tendency to produce ocular discomfort. In the second paper the application of the first of these tests to various lighting conditions was begun. Two purposes were had in making this application: (1) the studying and perfecting of the test itself for use in lighting work, which it is obvious could not be done effectively under one set or type of lighting conditions, and (2), the investigation of pertinent lighting effects, the results of which could be made both to serve as a guide for further work, and to provide cumulative data from which conclusions may be drawn as the conditions and stage of advancement of the work may warrant. This paper was divided into two sections. In

* A paper presented at the tenth annual convention of the Illuminating Engineering Society, Philadelphia, Pa., Sept. 18-20, 1916.

the first the test was applied to the determination of the effect on the eye of three lighting installations, direct, semi-indirect and indirect, so selected as to give wide differences in illuminating effects. In the second section the effect of six variations in intensity for the direct and semi-indirect installations was determined. In both of these cases the tests were all made at one position in the room, the point marked as the position of the observer in Fig. 1 of the present paper. Obviously, however, the effect of an unfavorable installation on the eye will vary with the position of the observer in the room. In the third paper, therefore, the tests were repeated for these installations at four positions in the room; the first with six reflectors in the field of view; the second with four; the third with two, and the fourth with none. The following features were also included; the work of the intensity series was completed, *i. e.,* six intensities of light were used with the indirect reflectors; a test was described for determining the effect on the fixation muscles of the eye and a series of miscellaneous experiments was conducted pertaining to the hygienic employment of the eye. In these experiments the following points were taken up: The effect of varying the area and the intrinsic brilliancy of the ceiling spots above the reflectors of the indirect system of lighting used; the effect of varying the angle at which the light falls on the work in a given lighting situation; the effect of using an opaque eye-shade with dark and light linings with a number of lighting installations; the effect on the efficiency of the fixation muscles of three hours of work under each of these installations; the effect of motion pictures on the eye for different distances of the observer from the projection screen; and a determination of the tendency of the different conditions of lighting used in these experiments to produce ocular discomfort, and a comparison of the tendency to produce discomfort and to cause loss of efficiency.

In the work of the second and third papers the influence of differences in the distribution factors, more especially surface brightness, was clearly revealed by wide variations in illumination effects. In the work of the fourth paper much smaller variations were employed. Such differences in effects were included as could be obtained by employing semi-indirect reflectors alone

ranging from medium to dense. Six sets of reflectors were used similar in size and shape but differing in density. These reflectors were all of the bowl type, 8 in. in diameter and 5⅜-5¾ in. deep. They were a pressed Sudan toned brown; a blown white glass toned brown (an experimental product); a pressed Sudan; a pressed Druid; a blown Veluria; and a blown white glass (also an experimental product). These reflectors were installed 30 in. from the ceiling in accord with the principles of indirect lighting. In the work of the present paper it was decided to use the same reflectors that were used in the work of the preceding paper with one omission because of close similarity to another in the series, and to install them in accord with the principles of direct lighting. It was decided also to supplement this series by experiments with totally opaque reflectors with different linings and of different dimensions and designs, and with one set of reflectors of prismatic glassware. Owing to the limited space allowed, we were compelled, however, to omit the results for the opaque reflectors from this paper. Both in the work of this and the preceding paper a number of interesting points with regard to the designing and installing of pendant reflectors have come up which we hope to make the subject of future work.

CONDITIONS TESTED.

The reflectors used were installed on the ceiling pendant in accord with the principles of direct lighting. As already stated they include all but one (the blown Veluria) of those used in the work of the immediately preceding paper, and in addition a set of reflectors of prismatic glassware differing somewhat from the others in size and design. They will be designated by the numerals I, II, III, IV, V and VI, numbered for convenience of treatment in the tables in the order of their effect on the eye from best to worst. Reflector I is the pressed Druid; reflector II, the blown white glass toned brown (experimental); reflector III, the blown white glass (experimental); reflector IV, the pressed Sudan; reflector V, the pressed Sudan toned brown; and reflector VI, the prismatic. The size and type of the first five of these reflectors have already been given. Reflector VI is of the extensive type, 8¾ in. in diameter and 5¾ in. deep. Reflectors I, IV, V, and VI are commercial products,

but II and III are experimental products inserted in the series to give gradations in density. The blown Veluria used in the former series of experiments was omitted from the present series because the illumination effects obtained and the effects on the eye, as determined in preliminary experiments, differed so little from those gotten from the blown white glass as to be considered of little significance for the present work. These reflectors were all used with 2¼ in., form "H" holders.

It has been our wish to conduct this investigation, as has been the case in all our work on the distribution factors, with the quality and intensity of the light made approximately the same. Unfortunately, with the materials available, the quality of the light could not be made in all cases uniformly alike. Tungsten lamps (full-frosted Mazda, type B) were used as light sources with each installation; but two of the reflectors, II and V, were not free from color. The density of these reflectors has been secured in part by giving them a brownish tone. Just how much effect this would have, if any, on the results of the tests we are not prepared at this time to say. The fact should be borne in mind, however, in considering the results obtained. It was decided to make the intensity of light as nearly equal as possible at the test object and to give a supplementary specification of the lighting effects in the remainder of the room.

At the test object the light was photometered in several directions. It was made approximately equal in the plane of the test object and as nearly as possible equal in the other directions. The specification of the lighting effects in the remainder of the room was accomplished as follows:

(1) A determination was made of the average illumination of the room under each set of reflectors. The room was laid out in 3 ft. (0.90 m.) squares and illumination measurements were made at 66 of the intersections of the sides of these squares. Readings were taken in a plane 122 cm. above the floor with the receiving test plate of the illuminometer in the horizontal, the 45° and 90° positions, measuring respectively the vertical, the 45° and the horizontal components of illumination. The 122 cm. plane was chosen because that was the height of the test object.

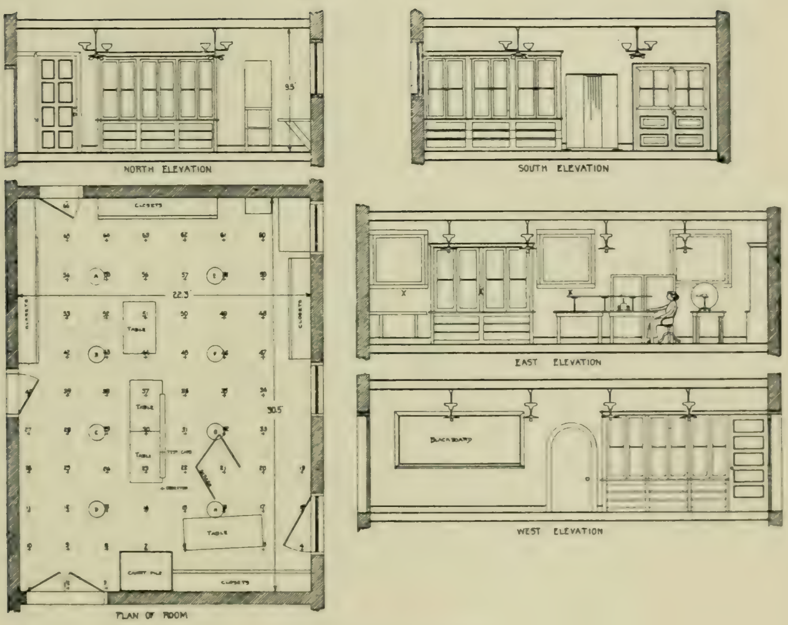


Fig. 1.—Plan of test room.

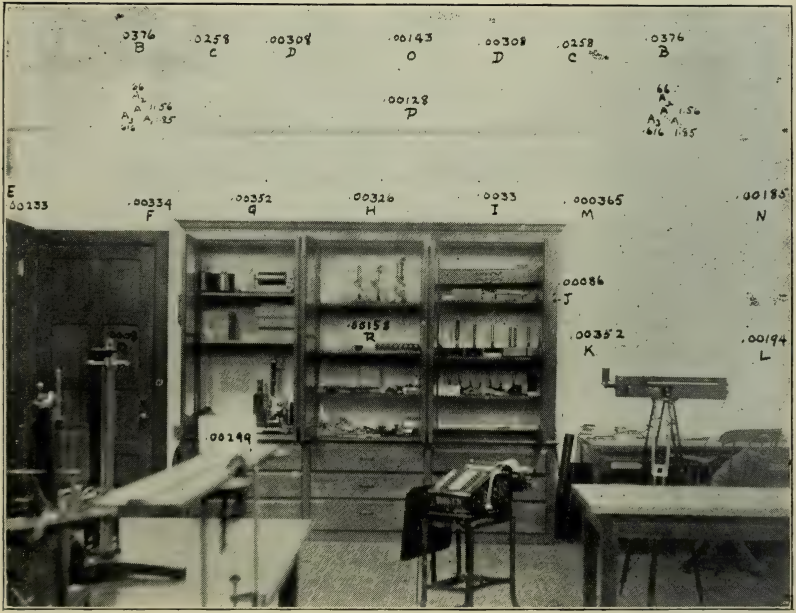


Fig. 2.—Showing the illumination effects in the north end of the room, Reflector I, and the brightness measurements having a very high or a very low brilliancy. This photograph was taken from a point directly behind the observer as near to the south wall of the room as was possible, and comprehends as much of the observer's field of view as could be included in the field of the camera.

(2) A determination was made of the brightness of prominent objects in the room, such as the test object, the reflectors, the openings of the reflectors, the reading page, the specular reflection from surfaces, etc. The brightness measurements were made with a Sharp-Millar photometer with the receiving test plate removed. The instrument was calibrated against a magnesium oxide surface obtained by depositing the oxide from the burning metal on a white card. By this method the reflecting surfaces were used as detached test plates. The readings were converted into candlepower per sq. in. by the following formula: Brightness = Foot candles/π x 144.

(3) Photographs were made of the room for each set of reflectors employed.

The tests were conducted in a room 30.5 ft. (9.29 m.) long, 22.3 ft. (6.797 m.) wide, and 9.5 ft. (2.895 m.) high. In Fig. 1 this room is shown drawn to scale: plan of room, north, south, east and west elevations. In the plan of room are shown the 66 stations at which the illumination measurements were made; and the position of the outlets for the lighting fixtures A, B, C, D, E, F, G and H. In the drawing east elevation the position of the observer at which the tests were taken is represented. So far in the work with these reflectors the tests have been taken at only one point in the room.

Table I gives the illumination measurements for the 66 stations represented in Fig. 1.[1] These measurements were made with the receiving test plate of the illuminometer in the horizontal, the vertical and the 45° planes, measuring respectively the vertical, the horizontal and the 45° components of illumination. Fig. 2 is taken from the series of photographs showing the illumination effects produced.[2] In the earlier papers, photographs of the room from three different positions were presented for each set of reflectors. In the present paper space has been allowed for the insertion of only one photograph, namely, for reflector I for the third of these positions. So limited a use of the photographic method of specification is of course valueless for comparative purposes. This photograph is inserted merely to show where the brightness measurements were made in case of the different sets of reflectors. In representing the brightness measurements in this photograph the spot meas-

ured is designated by a letter and the numerical value of the brightness measurement in candlepower per sq. in. is printed near by. The spots are lettered for convenience of reference in the tables of brightness measurements. This photograph was taken from a point directly behind the position of the observer as near to the south end of the room as was possible; and although not all of the observer's field of view was covered by the brightness measurements made, owing to the narrow field of the camera as compared with the binocular field, still the order of magnitude of brightness differences present in the field of view is well represented by these measurements.

TABLE I.

Showing the illumination measurements in foot-candles for each of the 66 stations represented in Fig. 1 for the six types of translucent reflector used.

Division A.

	Vertical, reflector type			Horizontal, reflector type			45°, reflector type		
Station	I	II	III	I	II	III	I	II	III
1	1.50	1.34	1.31						
2	1.75	1.40	1.50						
3	1.68	1.49	1.39						
4	2.75	2.70	2.75						
5	3.20	3.20	3.60						
6	3.20	2.80	2.90						
7	3.0	3.15	3.10						
8	3.50	4.0	3.85						
9	3.20	3.35	2.95						
10	1.96	1.88	1.58						
11	2.38	2.10	2.10						
12	4.25	4.20	4.40	0.52	0.38	0.38	2.15	2.30	2.30
13	5.20	6.60	5.60	0.38	0.32	0.31	2.35	3.25	2.70
14	4.40	4.45	4.30	0.35	0.30	0.32	2.20	2.30	2.20
15	4.10	3.75	4.10	0.43	0.30	0.37	2.0	1.76	1.94
16	4.60	4.70	4.90	0.46	0.27	0.34	2.15	2.20	2.40
17	3.70	4.0	3.90	0.43	0.28	0.36	1.75	1.72	2.0
18	2.35	2.25	2.10	0.52	0.45	0.48	1.18	1.18	1.17
19	3.30	3.1	2.90	1.08	1.18	1.05	1.96	2.15	1.88
20	4.75	5.0	4.60	1.18	1.30	1.20	2.90	3.20	2.90
21	5.60	6.0	5.70	1.44	1.39	1.45	3.40	3.75	3.50
22	5.10	4.75	5.20	1.40	1.25	1.37	3.10	3.0	3.20
23	5.40	5.20	5.40	1.31	1.34	1.45	3.20	3.40	3.30
24	6.0	6.60	6.20	1.58	1.72	1.62	3.70	4.40	3.80

TABLE I.—(*Continued.*)

Station	Vertical, reflector type I	II	III	Horizontal, reflector type I	II	III	45°, reflector type I	II	III
25	5.10	4.90	5.60	1.36	1.20	1.38	3.35	3.10	3.30
26	2.80	2.50	2.70						
27	3.20	2.90	2.80						
28	5.10	5.15	5.30	1.44	1.28	1.35	3.60	3.50	3.40
29	6.10	6.70	6.90	1.78	1.56	1.72	4.20	4.40	4.90
30	5.40	5.90	5.60	1.58	1.51	1.53	3.90	3.90	3.90
31	5.30	5.20	5.0	1.60	1.43	1.51	3.65	3.75	3.35
32	5.90	6.50	6.20	1.75	1.61	1.65	4.30	4.50	4.20
33	4.85	5.40	4.80	1.63	1.48	1.48	3.70	3.80	3.50
34	5.0	5.0	5.0	2.15	2.0	1.87	3.80	3.60	3.50
35	6.0	6.20	6.20	2.40	2.20	2.20	4.50	4.30	4.40
36	5.20	5.10	5.20	2.10	1.97	2.02	4.0	3.70	3.80
37	5.20	5.60	5.20	2.20	2.15	2.15	4.10	4.15	4.20
38	5.80	6.60	6.60	2.30	2.20	2.50	4.40	4.70	4.90
39	4.70	5.20	4.75	2.05	1.92	1.96	3.80	3.75	3.80
40	2.65	3.05	2.45						
41	2.30	2.75	2.35						
42	4.70	5.20	4.80	1.88	1.92	1.75	3.70	4.0	3.70
43	5.50	6.70	6.50	2.20	2.15	2.20	4.50	5.0	5.0
44	5.38	5.40	5.50	2.20	2.0	2.10	4.10	4.35	4.50
45	5.0	4.90	4.90	2.16	1.94	2.0	4.10	3.80	4.10
46	5.50	6.40	6.70	2.15	2.10	2.20	4.40	4.70	5.0
47	4.80	5.0	4.90	2.03	1.84	1.98	3.90	3.75	4.0
48	4.50	5.0	4.70	2.25	2.10	2.30	3.80	3.90	4.0
49	5.40	6.20	6.0	2.80	2.40	2.75	4.60	4.60	4.90
50	4.60	4.90	4.90	2.60	2.30	2.45	4.10	4.20	4.30
51	4.90	5.15	5.0	2.35	2.25	2.40	4.30	4.15	4.30
52	5.50	6.0	6.20	2.50	2.40	2.65	4.50	4.80	4.90
53	4.70	4.80	5.20	2.20	2.10	2.20	3.80	4.0	4.15
54	4.30	4.60	4.90	2.10	1.88	2.10	4.40	3.95	4.15
55	5.20	5.20	6.20	2.50	2.05	2.30	4.90	4.30	5.20
56	4.70	4.50	4.60	2.40	2.10	2.20	4.50	4.10	4.10
57	4.30	4.40	4.20	2.30	2.0	2.10	4.20	4.0	4.0
58	4.90	6.20	5.50	2.40	2.15	2.40	4.40	5.10	4.90
59	3.80	4.80	4.0	2.12	1.82	1.80	3.60	4.20	3.50
60	3.0	3.30	3.0	2.30	2.15	1.96	3.80	3.90	3.55
61	3.40	4.30	3.70	2.70	2.80	2.40	4.30	5.20	4.25
62	3.0	3.0	2.90	2.50	2.25	2.35	4.0	3.70	3.50
63	3.10	3.05	3.20	2.75	2.25	2.50	4.2	3.65	4.20
64	3.50	3.50	3.10	2.70	2.55	2.60	4.30	4.30	4.10
65	3.10	3.10	4.10	2.40	2.10	2.70	3.90	3.70	4.90
66	1.40	1.29	1.28						
Average	4.18	4.39	4.27	1.685	1.69	1.77	3.565	3.74	3.75

TABLE I.—(*Continued.*)

Division B.

Station	Vertical, reflector type			Horizontal, reflector type			45°, reflector type		
	IV	V	VI	IV	V	VI	IV	V	VI
1	1.50	1.32	1.36						
2	1.52	1.48	1.46						
3	1.54	1.51	1.38						
4	2.80	3.0	3.60						
5	3.60	3.50	2.0						
6	3.25	2.95	2.70						
7	3.80	3.20	2.90						
8	4.60	3.80	3.60						
9	3.60	3.0	3.20						
10	1.88	1.76	1.68						
11	2.20	2.15	2.20						
12	4.40	4.15	4.40	0.40	0.32	0.43	2.50	2.10	2.15
13	6.60	5.80	4.70	0.31	0.29	0.35	3.50	2.70	2.30
14	4.70	4.50	4.0	0.31	0.25	0.32	2.40	2.0	1.92
15	4.20	3.90	3.80	0.30	0.28	0.38	1.94	1.82	1.72
16	5.50	5.60	4.40	0.37	0.37	0.36	2.75	2.65	2.0
17	4.30	4.60	3.65	0.36	0.32	0.42	2.20	2.25	1.78
18	2.70	2.35	2.20	0.47	0.53	0.54	1.32	1.45	1.20
19	3.10	3.60	3.0	1.10	1.30	1.20	2.10	2.30	2.10
20	5.0	5.60	4.80	1.34	1.40	1.26	3.20	3.35	3.10
21	5.80	6.20	5.80	1.45	1.56	1.45	3.80	3.38	3.60
22	5.0	4.90	4.80	1.30	1.49	1.28	3.30	3.0	3.0
23	5.30	5.0	4.50	1.35	1.29	1.36	3.30	3.15	3.10
24	6.60	6.10	6.40	1.78	1.50	1.64	4.40	3.90	4.20
25	5.20	4.75	4.95	1.25	1.42	1.18	3.30	2.90	2.80
26	2.85	2.75	2.25						
27	3.0	2.95	2.75						
28	5.15	5.10	5.0	1.50	1.35	1.54	3.80	3.40	3.60
29	7.0	6.70	6.0	1.70	1.70	1.65	5.10	4.50	4.20
30	5.80	5.40	4.80	1.60	1.48	1.42	4.20	3.70	3.50
31	5.40	4.90	4.80	1.47	1.44	1.43	3.80	3.60	3.30
32	6.60	6.40	5.20	1.66	1.70	1.58	4.75	4.60	3.60
33	5.40	5.10	4.40	1.50	1.53	1.35	3.90	3.85	3.10
34	4.80	4.70	4.70	2.0	1.90	1.94	3.90	3.60	3.50
35	6.0	6.30	5.30	2.20	2.40	1.92	4.40	4.70	3.70
36	5.10	4.70	4.50	2.10	2.05	1.79	3.75	3.60	3.40
37	5.50	5.40	4.95	2.30	2.05	2.0	4.30	3.90	3.80
38	6.40	6.40	5.80	2.30	2.32	2.25	4.90	4.60	4.20
39	4.65	5.0	4.85	2.10	1.96	1.86	3.75	3.80	3.60
40	3.10	2.80	2.65						
41	2.50	2.50	2.30						
42	5.30	5.10	4.20	1.99	1.79	1.80	4.20	4.0	3.40

TABLE I.—(*Continued.*)

Station	Vertical, reflector type IV	V	VI	Horizontal, reflector type IV	V	VI	45°, reflector type IV	V	VI
43	6.40	6.80	5.20	2.30	2.0	2.15	4.90	4.90	4.10
44	5.40	5.30	4.60	2.20	1.99	1.90	4.20	4.10	3.80
45	4.90	4.90	4.90	2.0	2.0	2.0	4.10	4.0	3.90
46	6.40	6.90	5.40	2.10	2.55	2.10	5.20	5.30	4.30
47	5.40	5.10	4.80	1.92	2.0	1.92	4.30	4.15	3.75
48	5.20	4.90	4.60	2.28	2.20	2.25	4.20	3.90	4.0
49	6.0	6.10	5.50	2.70	2.6	2.42	4.90	4.65	4.40
50	4.90	4.72	4.70	2.50	2.35	2.40	4.20	3.90	4.10
51	5.0	5.50	4.80	2.60	2.40	2.40	4.30	4.15	4.0
52	6.0	6.30	5.90	2.70	2.50	2.40	4.90	5.0	4.30
53	4.70	4.90	4.90	2.20	2.22	2.05	3.70	3.90	3.60
54	4.50	5.10	5.20	1.90	1.90	1.90	4.10	4.30	4.10
55	5.40	6.30	5.80	2.20	2.25	2.30	4.70	5.30	4.80
56	4.70	4.80	4.80	2.20	2.30	2.20	4.20	4.65	4.40
57	4.45	4.70	4.10	2.10	2.15	2.20	4.20	4.25	3.90
58	6.10	6.20	4.40	2.20	2.30	2.30	5.50	5.50	4.20
59	4.70	5.0	3.80	1.84	1.96	1.90	4.10	4.42	3.50
60	3.30	3.50	3.0	2.10	2.20	2.0	3.80	4.0	3.60
61	4.60	3.95	3.25	2.50	2.85	2.30	5.20	5.0	3.90
62	3.0	3.15	2.80	2.40	2.60	2.30	3.80	4.15	3.50
63	3.0	3.10	3.10	2.40	2.60	2.40	3.70	4.10	4.0
64	3.40	3.90	3.90	2.60	2.95	2.70	4.20	4.90	4.80
65	2.90	3.05	3.50	2.20	2.10	2.35	3.60	3.95	4.20
66	1.31	1.44	1.42						
Average	4.50	4.43	4.035	1.79	1.78	1.71	3.895	3.825	3.50

In Table II are given the brightness measurements for the six sets of reflectors. This table also includes the letters identifying the measurements with the spots measured as shown in Fig. 2. In making the brightness measurements of the reflectors, the openings and such parts of the lamp as showed in the openings the illuminometer was supported in such a position that the opening of the receiving arm was about 4 in. (10.16 cm.) from the surface to be measured and the receiving arm itself was lined up as nearly as could be with the observer's eye in position at the point of work. The surface measured was thus, roughly speaking, the surface that was imaged in the observer's eye during the test period. The surface of some of the reflectors presented so much unevenness of brightness that overlapping measurements were made and an average taken. These average values are given in Table II.[8]

TABLE II.

Showing the brightness measurements in candlepower per square inch for the surfaces *A*, *B*, *C*. *D*, etc. (Fig. 2), the test object and reading page for the six types of translucent reflector used. These measurements were made with the illuminometer close to the surface measured and with its receiving arm lined up with the eye of the observer in position at the point of work. A = brightness of spot on lamp due to filament; A_1 = brightness of tip of lamp; A_2 = brightness of outside of reflector; and A_3 = brightness of opening of reflector.

Surface measured	Reflector Type I	Reflector Type II	Reflector Type III	Reflector Type IV	Reflector Type V	Reflector Type VI
A	11.56	13.20	11.56	11.80	12.09	10.20
A_1	1.85	2.11	1.85	1.89	1.932	1.63
A_2	0.66	0.374	0.924	0.4004	0.275	2.05
A_3	0.616	0.924	1.23	1.364	1.87	0.0617
B	0.0376	0.0252	0.0483	0.0268	0.0263	0.0209
C	0.0258	0.00794	0.0241	0.0107	0.01154	0.0177
D	0.00308	0.00185	0.0029	0.00207	0.00167	0.00317
E	0.00233	0.00163	0.00202	0.00132	0.00119	0.00264
F	0.00334	0.00194	0.00295	0.00198	0.00198	0.00378
G	0.00352	0.00211	0.00304	0.00202	0.00194	0.00422
H	0.00326	0.00196	0.00273	0.00189	0.00176	0.0037
I	0.0033	0.00198	0.00264	0.00198	0.00186	0.00392
J	0.00086	0.00082	0.0008	0.00086	0.00082	0.00099
K	0.00352	0.00308	0.00299	0.00334	0.00348	0.0036
L	0.00194	0.00145	0.00158	0.00136	0.00149	0.00207
M	0.00365	0.00246	0.00304	0.00233	0.00224	0.00431
N	0.00185	0.00136	0.0015	0.00132	0.00106	0.00207
O	0.00143	0.00108	0.00132	0.0012	0.00103	0.00167
P	0.00128	0.00095	0.00114	0.00087	0.00087	0.0015
Q	0.0008	0.0007	0.00068	0.0008	0.00069	0.00081
R	0.00158	0.00132	0.00136	0.00128	0.00123	0.00189
Test object	0.00299	0.00290	0.00299	0.00304	0.00291	0.0030
Reading page horizontal	0.00726	0.00761	0.00713	0.00770	0.00748	0.00713
Reading page 45° position	0.00422	0.00414	0.00431	0.00405	0.00414	0.00460

In Tables III and IV are shown some prominent ratios of surface brightness for the six sets of reflectors. In compiling these ratios it has been considered important to make a comparative showing for the different types of reflectors (*a*) of the extremes of surface brightness and (*b*) the relation of the brilliancy of objects in the surrounding field to the surface brightness at the point of work. Extremes of surface brightness are shown by giving the ratios between the surfaces of the first, second, third, etc., order of brilliancy and the lowest order of brilliancy; and the comparison of brilliancy of objects in the surrounding field to the brightness at the point of work by giving the ratios of the first, second and third order of brilliancy to the brightness of the test objects and the reading page in the working position.

TABLE III.

Ratios showing the extremes of surface brightness for the six types of translucent reflector used.

Division A.

Ratio	Reflector Type I	Reflector Type II	Reflector Type III
Lightest to darkest	11.56 /0.0008 = 14.450	13.20 /0.0007 = 18,857	11.56 /0.00068 = 17,000
2nd lightest to darkest......	1.85 /0.0008 = 2,312.5	2.11 /0.0007 = 3,014.3	1.85 /0.00068 = 2,721
3rd lightest to darkest......	0.66 /0.0008 = 825	0.924 /0.0007 = 1,320	1.23 /0.00068 = 1,809
4th lightest to darkest......	0.616 /0.0008 = 770	0.374 /0.0007 = 534	0.924 /0.00068 = 135.88
5th lightest to darkest......	0.0376 /0.0008 = 47	0.0252 /0.0007 = 36	0.0483 /0.00068 = 71.03
6th lightest to darkest......	0.0258 /0.0008 = 32.25	0.00794/0.0007 = 11.34	0.0241 /0.00068 = 35.44
7th lightest to darkest......	0.00365/0.0008 = 4.56	0.00308/0.0007 = 4.4	0.00304/0.00068 = 4.47
8th lightest to darkest......	0.0035 /0.0008 = 4.38	0.00246/0.0007 = 3.51	0.00304/0.00068 = 4.47
9th lightest to darkest......	0.0035 /0.0008 = 4.38	0.0021 /0.0007 = 3.0	0.00299/0.00068 = 4.40
10th lightest to darkest......	0.00334/0.0008 = 4.18	0.00198/0.0007 = 2.83	0.00295/0.00068 = 4.34

Division B.

Ratio	Reflector Type IV	Reflector Type V	Reflector Type VI
Lightest to darkest	11.80 /0.0008 = 14,750	12.09 /0.00069 = 17,522	11.20 /0.00081 = 12,593
2nd lightest to darkest......	1.89 /0.0008 = 2,362.5	1.932 /0.00069 = 2,800	2.05 /0.00081 = 2,531
3rd lightest to darkest......	1.364 /0.0008 = 1,705.0	1.87 /0.00069 = 2,710	1.63 /0.00081 = 2,012.35
4th lightest to darkest......	0.4004 /0.0008 = 500.5	0.275 /0.00069 = 398.6	0.617 /0.00081 = 76.17
5th lightest to darkest......	0.0268 /0.0008 = 33.5	0.0263 /0.00069 = 38.12	0.0209 /0.00081 = 25.81
6th lightest to darkest......	0.0107 /0.0008 = 13.38	0.01154/0.00069 = 16.72	0.0177 /0.00081 = 21.85
7th lightest to darkest......	0.00334/0.0008 = 4.18	0.00348/0.00069 = 5.04	0.00431/0.00081 = 5.32
8th lightest to darkest......	0.00233/0.0008 = 2.91	0.00224/0.00069 = 3.25	0.00422/0.00081 = 5.21
9th lightest to darkest......	0.00207/0.0008 = 2.59	0.00198/0.00069 = 2.87	0.00392/0.00081 = 4.84
10th lightest to darkest......	0.00202/0.0008 = 2.53	0.00194/0.00069 = 2.81	0.00378/0.00081 = 4.59

TABLE IV.

Ratios showing the relation of the brilliancy of objects in the surrounding field to the surface brightness at the point of work for the six types of translucent reflector used.

Division A.

Ratio	Reflector Type I	Reflector Type II	Reflector Type III
Lightest to test object........	11.56 /0.00299 = 3,866	13.20 /0.0029 = 4,552	11.56 /0.00299 = 3,866
Lightest to reading page......	11.56 /0.00422 = 2,739	13.20 /0.00414 = 3,188.4	11.56 /0.00431 = 2,682
2nd lightest to test object.....	1.85 /0.00299 = 618.7	2.11 /0.0029 = 727.58	1.85 /0.00299 = 618.7
2nd lightest to reading page..	1.85 /0.00422 = 438.4	2.11 /0.00414 = 509.6	1.85 /0.00431 = 429.2
3rd lightest to test object.....	0.66 /0.00299 = 220.73	0.924/0.0029 = 318.6	1.23 /0.00299 = 411.4
3rd lightest to reading page...	0.66 /0.00422 = 156.4	0.924/0.00414 = 223.2	1.23 /0.00431 = 285.4
4th lightest to test object.....	0.616 /0.00299 = 206.0	0.374/0.0029 = 129.0	0.924 /0.00299 = 309.0
4th lightest to reading page...	0.616 /0.00422 = 146.0	0.374/0.00414 = 90.3	0.924 /0.00431 = 214.4

Division B.

Ratio	Reflector Type IV	Reflector Type V	Reflector Type VI
Lightest to test object........	11.80 /0.00304 = 3,881.6	12.09 /0.00291 = 4,154.6	10.20 /0.0030 = 3,400
Lightest to reading page.....	11.80 /0.00405 = 2,913.6	12.09 /0.00414 = 2,920.3	10.20 /0.0046 = 2,217.4
2nd lightest to test object.....	1.89 /0.00304 = 621.7	1.932/0.00291 = 663.9	2.05 /0.0030 = 683.3
2nd lightest to reading page...	1.89 /0.00405 = 466.67	1.932/0.00414 = 466.67	2.05 /0.0046 = 445.7
3rd lightest to test object.....	1.364 /0.00304 = 448.7	1.87 /0.00291 = 642.6	1.63 /0.0030 = 543.3
3rd lightest to reading page...	1.364 /0.00405 = 336.8	1.87 /0.00414 = 451.7	1.63 /0.0046 = 354.35
4th lightest to test object.....	0.4004/0.00304 = 131.7	0.275/0.00291 = 94.5	0.0209/0.0030 = 6.97
4th lightest to reading page...	0.4004/0.00405 = 98.9	0.275/0.00414 = 66.9	0.0209/0.0046 = 4.54

As was stated earlier in the paper, the effect of a harmful installation on the ability of the eye to maintain its efficiency for a period of work varies with the position of the observer in the room. In the work for the second and third papers, the tests were made at four positions in which respectively six, four, two and no reflectors were in the field of view. This variation of the position from which the observation is made accomplishes two purposes: (1) It gives us a more representative idea of the difference of the effect on the eye of the different types of lighting used; and (2) it shows the effect of varying the number of surfaces in the field of view showing brightness differences, particularly the number of primary sources. So far we have been able to conduct the tests for the reflectors used in this work at only one of these positions, namely, the one with six reflectors in the field of view. Later we hope to repeat the tests for at least a part of these reflectors at the other three positions. Not only does the effect of a given lighting installation on the eye vary with the number of reflectors in the field of view, but the effect of each reflector varies with its degree of excentricity in the field of view. We have given below, therefore, the angle of elevation of each reflector above the working plane (the 122 cm. level in these experiments). The angle is measured from the working plane to a line connecting the center of the opening of the reflector at outlets *A, B* and *C* (Fig. 1) with the eye in the working position. The value of this angle for reflectors I, IV, V and VI at outlet *A* is 14° 55′; at outlet *B* 22° 20′; and at outlet *C* 42° 39′. Its value for reflectors II and III at outlet *A* is 14° 52′; at outlet *B* 22° 15′; and at outlet *C* 42° 35′.

In the selection and use of observers for this work care was exercised in the first place to choose only those who had already shown a satisfactory degree of precision in other work of physiological optics and whose clinic record showed no uncorrected defects of consequence.[4] All were under 30 years of age. Before being allowed to take part in the actual work of testing each observer was trained to a satisfactory degree of precision in the 3-min. records under a given lighting condition and in the 3-hr. test under several conditions. In the actual work of testing the results were compiled from a number of observations and the precision was checked up by the size of the mean variation.

No results were accepted as significant unless the variation produced by changing the conditions to be tested was largely in excess of the mean error or mean variation for each condition tested. This is the accepted conventional check in work of this kind on the influence of variable extraneous factors and was carefully applied at every step in the work. For a fuller statement of the precautions that have been used in this and the previous work to secure reproducibility of results and to guard against the influence of variable extraneous factors, see especially pp. 1122-1130 of the paper immediately preceding this.

The results for the effect on the eye are given in Table V. The values given in this table are averaged in each case from the results of a number of 3-hr. tests, and are typical of the results obtained from all of our observers. In order to show the reproducibility of the results obtained and to determine whether the variations produced by the changes in lighting effects, are safely in excess of the variation in the test itself subject to all the variable factors which may influence it, the mean variations from the average result have been computed in each case. The value of these in per cent. is given in columns 15 and 16 in Table V. This value has been estimated in two ways. In column 16 it is based on the results sought, namely, the mean value of the drop in ratio of time seen clear to time seen blurred. Computed in this way the result indicates whether or not each individual determination has been made with an acceptable degree of precision as compared with other work of its class. In column 15 it is based on 3.5. Computed in this way the results appear in a form from which it can be readily determined whether or not the work has been done with a degree of precision which is acceptable for the comparative work which is the special purpose of these experiments. That is, to be acceptable in this regard the variation of the drop in ratio caused by changing the conditions to be tested must in each case, if a positive result is to be claimed for the change, be safely in excess of the mean variation. To make this comparison convenient the drop in ratio and the mean variation have both been estimated in per cent. on the same base, namely 3.5.

TABLE V.

Showing the tendency of the six types of translucent reflector used to cause loss of visual efficiency, or power to sustain clear seeing.

Type of reflector	Watts	Volts	Intensity foot-candles			Time	Maximal distance at which test object can be seen clear	Working distance	Total time clear	Total time blurred	Total time clear ÷ total time blurred	Ratios reduced to common standard	Loss of efficiency expressed in percentage change of ratio	Mean variation (per cent.)	
			Vertical	Horizontal	45°									Based on 3.5	Based on result sought (drop in ratio)
I	800	110	5.0	1.47	3.3	9 A. M.	78.0	59.0	136	44	3.09	3.5			
						12 M.	77.5	59.0	121.5	58.5	2.08	2.35	32.9	0.8	2.77
II	800	113	4.84	1.43	3.35	9 A. M.	78.5	60.0	140	40	3.5	3.5			
						12 M.	77.5	60.0	119.5	60.5	1.975	1.975	43.6	0.6	1.38
III	800	110	5.0	1.44	3.4	9 A. M.	77.5	59.5	142	38	3.74	3.5			
						12 M.	76.5	59.5	121	59	2.05	1.92	45.0	0.82	1.70
IV	800	110.5	5.0	1.44	3.4	9 A. M.	77.5	59.0	135	45	3.0	3.5			
						12 M.	76.5	59.0	107	73	1.466	1.71	51.0	1.74	3.97
V	800	111	4.8	1.44	3.3	9 A. M.	77.5	60.0	138	42	3.29	3.5			
						12 M.	76.5	60.0	95	85	1.12	1.19	66.0	0.63	1.02
VI	800	107	5.1	1.47	3.4	9 A. M.	77.5	60.0	138.3	41.7	3.32	3.5			
						12 M.	76.5	60.0	84.7	95.3	0.89	0.938	73.2	0.414	0.60

In Fig. 3, Chart *A*, a graphic representation is made of the results of Table V. In constructing these curves the total length of the test period is plotted along the abscissa and the ratio of the time the test object is seen clear to the time it is seen blurred in the 3-min. record before and after work is plotted along the ordinate. Each one of the large squares along the abscissa represents one hour of the test period, and along the ordinate, an integer of the ratio.

So far in all of our work we have shown for the sake of completeness of representation the gradations of surface brightness in three ways. (1) Brightness measurements of prominent surfaces have been made. (2) Ratios have been given between surfaces of the first, second, third, etc., order of brilliancy and surfaces of the lowest order of brilliancy; and between surfaces of the first, second and third order of brilliancy and the brightness at the point of work. (3) In all of the previous papers the mean variation from the average and the percentage of mean variation have been shown. In the consideration of these specifications a number of single items might be selected as of possible significance in relation to the effect on the eye. Among these may be mentioned the order of magnitude of the highest brilliancies; the average brilliancy, the ratio of the highest to the lowest order of brilliancy; the ratio of the highest order of brilliancy to the average brilliancy; the ratio of the average to the lowest order of brilliancy; the ratio of the highest order of brilliancy to the brilliancy at the point of work (brightness of test object and reading page), etc. In order to see which of these correlate most closely with the results of the test for tendency to cause loss of power to sustain clear seeing, charts are constructed in which some of these features are plotted against the results of the test. These charts are given in Figs. 3 and 4. In Fig. 3, Chart *B*, per cent. loss in power to sustain clear seeing is plotted against the highest order of brilliancy that varies by considerable amounts from installation to installation, namely, the brightness of the reflector—outer surface and opening. In Fig. 4 are grouped the remainder of the charts.

Three points may be noted perhaps with reference to these charts. (1) The prismatic reflectors which differ in design from

the rest of the series, more or less conspicuously fall out of the curve in every case but two. The effect of difference in design on the smoothness of the curve comes out especially in the results for the opaque reflectors (to be given in the next paper of the series) in which case there are marked differences in both size and design. All of the curves plotted on the above bases are very irregular in case of these reflectors, with the exception of separate curves for three, which are similar in design. Reasons for this irregularity are perhaps (*a*) the method of specifying bright-

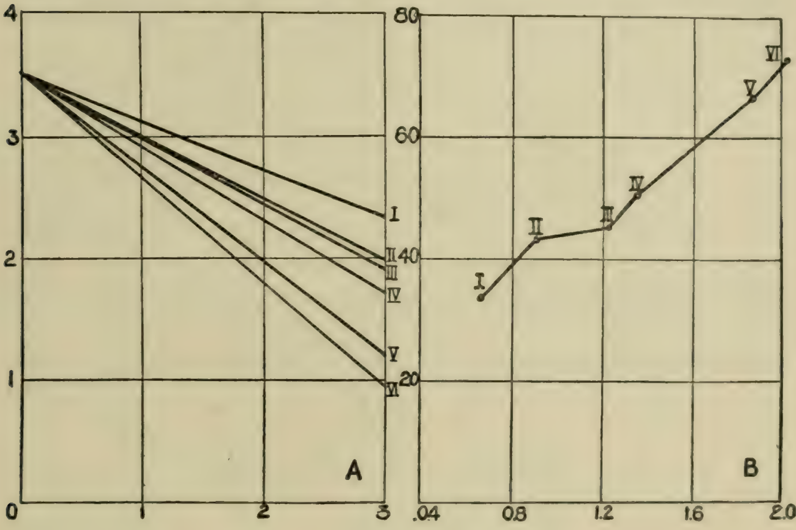


Fig. 3.

Showing the tendency of the six types of translucent reflector to cause loss of visual efficiency or power to sustain clear seeing. In Chart *A* ratio time clear to time blurred is plotted against length of test period; and in Chart *B* percentage drop in ratio time clear to time blurred is plotted against highest brightness of reflector in candlepower per square inch.

Reflector	Volts	Foot-candles Vertical	Foot-candles Horizontal	Foot-candles 45°	Candlepower per square inch
Type I	110	5.0	1.47	3.30	0.66
Type II	113	4.84	1.43	3.35	0.924
Type III	110	5.0	1.44	3.40	1.23
Type IV	110.5	5.0	1.44	3.40	1.364
Type V	111	4.80	1.44	3.30	1.87
Type VI	107	5.10	1.47	3.40	2.05

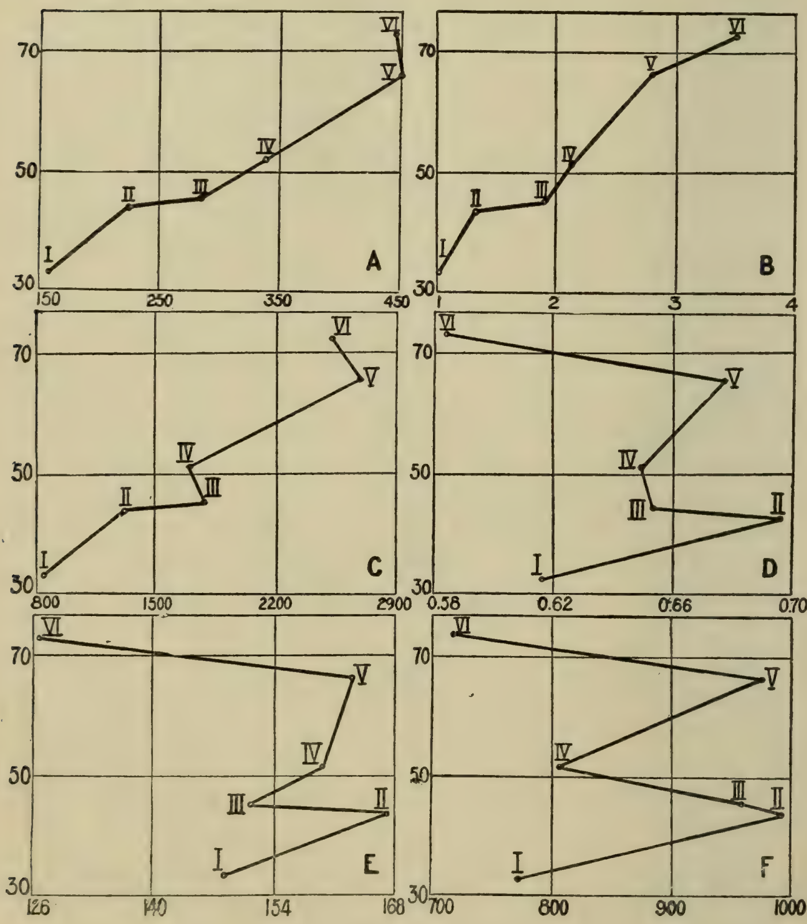


Fig. 4.

Showing the tendency of the six types of translucent reflector to cause loss of visual efficiency or power to sustain clear seeing. In Chart *A*, percentage drop in ratio time clear to time blurred is plotted against ratio of highest brightness of reflector to brightness at point of work; in *B*, against ratio of highest brightness of reflector to average brightness; in *C*, against ratio of highest brightness of reflector to darkest surface in field of view; in *D*, against average brightness; in *E*, against ratio of average brightness to brightness at point of work; and in *F*, against ratio of average brightness to darkest surface in the field of view.

ness. We are inclined to believe that if the values of the surfaces of high brilliancy, which vary considerably in area in case of the opaque reflectors, were given in total candlepower instead of candlepower per square inch, they and the ratios based on them would correlate more closely with the effects on the eye. (*b*) The angle of presentation to the eye. The openings of the different types of opaque reflector differ in their distances above the working plane. And (*c*) the number of factors varied. Brightness is not the only one of the distribution factors varied in considerable amounts by the different types of opaque reflectors. (2) The greater regularity of the curves is rather strikingly marked in which the highest order of brilliancy that varies by considerable amounts or the ratios in which this quantity appears, is plotted against the results of the test. This it will be remembered was true also of the work of the former paper. (3) The range of brightness for the work of this paper is quite a little higher in the scale than for that of the former paper with the same reflectors. This fact should be borne in mind, for example, in comparing the shape of the curves for the two papers in which highest order of variable brilliancy is plotted against the results of the tests. In this paper, for example, the curve begins at a point, 0.66 candlepower per square inch, which is well above the knee of the former curve. That is, the two curves are in general quite similar in shape when they are compared for the same range of brightness values. The former curve has, however, the greater regularity; but in connection with this fact it should be borne in mind that a variation of the brightness factor in separation can be more nearly accomplished with these reflectors when they are installed inverted than when they are installed pendant.

In the former paper another method of evaluating the results of the test was employed in addition to the one used above. In this method the ratio of the time seen clear to the total time of the observation is taken as the measure of the ability of the eye to sustain clear seeing at the time the test is taken. For the sake of again comparing this method of evaluation with the one we have used in the rest of the paper, a chart has been prepared (omitted from this paper because of lack of space) in which ratio time clear to total time of observation is plotted against length of test period. A comparison of this chart with Fig. 3,

TABLE VI.

Showing a comparison of the tendency of the six types of translucent reflector used to cause loss of visual efficiency and to produce ocular discomfort. The tendency to produce discomfort is estimated by the time required for just noticeable discomfort to be set up.

Type of reflector	Volts	Foot-candles			Per cent. loss of efficiency	Mean variation (per cent.)	Time limen of discomfort in seconds (not reading)	Mean variation (per cent.)	Change produced by changing type of reflector (per cent.)	Time limen of discomfort in seconds (reading)	Mean variation (per cent.)	Change produced by changing type of reflector (per cent.)
		Vertical	Horizontal	45°								
I	110	5.0	1.47	3.3	32.9	0.80	69.2	1.73		34.2	0.6	
II	113	4.85	1.43	3.35	43.6	0.60	52.8	0.94	23.8	19.3	5.0	43.6
III	110	5.0	1.44	3.4	45.0	0.82	40.2	1.99	23.9	16.5	3.03	14.5
IV	110.5	5.0	1.44	3.4	51.0	1.74	36.3	2.5	9.7	15.0	2.9	9.1
V	111	4.8	1.44	3.3	66.0	0.63	20.45	1.34	43.7	9.4	4.25	37.3
VI	107	5.1	1.47	3.4	73.2	0.414	12.8	3.2	37.4	8.2	1.45	12.8

Chart *A*, shows the same order of rating of the reflectors, but a slight change in the position in the scale given to some of the reflectors. For the purpose of discovering what is the best way of treating the results of the tests, several methods have been employed. Up to and including the present paper, however, only three of them have been given in print; ratio of time clear to time blurred, ratio of time clear to total time of observation, and the per cent. of drop in the ratio of time clear to time blurred. An ultimate decision with regard to what is the best method of treatment of results can come perhaps only later in the work with the consideration of a larger number of cases.

As formerly, the work was concluded by determining for the six types of reflectors the relative tendencies to produce ocular discomfort. Two cases were made of this determination; one when the eye was at rest, and the other when it was at work. A description of how the determinations were made and a discussion of the method that was used has been given in a previous paper. The results are shown in Table VI. In this table are given also, for the sake of comparison, results expressing the tendency of each type of reflector to cause loss of ability to sustain clear seeing.

APPENDIX.

The reflectors used in this work were supplied by the Ivanhoe-Regent Works of the General Electric Company, with special reference to the needs and purpose of the investigation. In considering the results it should be borne in mind that these reflectors have been used to produce certain variations in illumination effects, and that the work has not been conducted as a specific test of reflectors. For example, in order to secure in all cases approximately equal illumination at the test object, the lamps had to be operated at higher voltages for some reflectors than for others. This produced for the different reflectors slightly different relative brightness values for outer surface and opening than would have been obtained had the lamps all been operated at the same voltage. Also clear and bowl-frosted lamps are more commonly used with these reflectors than full frosted lamps. One effect of using clear or bowl-frosted lamps with them in this work would have been to have increased the brightness of both

opening and outer surface of the reflectors, and to have given, there is good reason to believe, a correspondingly uniformly poorer result for the eye. It is never entirely safe to predict results under conditions differing even slightly from what have been used, but from data at hand there is no reason to think that the change would have produced any significant difference in the relative rating of these reflectors. The full frosted lamps were used for two reasons: (*a*) to test the whole group of reflectors under conditions as favorable as possible for the eye. This, admittedly, is only one point of view; the results might have had more direct practical bearing had clear or bowl-frosted lamps been used. And (*b*), which is the chief reason, for the sake of making the work as far as possible comparable with the previous work, we desired to make the illumination of the test object as nearly equal as could be for the different reflectors, translucent and opaque, and equal to that used in the former work. This was best accomplished by the selection of lamps made.[5]

NOTES.

[1] A marked characteristic of the effects produced by the dense and completely opaque reflectors was the low illumination of the ceiling and upper part of the room, and the high and in some cases almost glaring illumination of the floor and objects in the working plane. So far as the effects on the eye of the kind registered by our tests are concerned, however, these inequalities of illumination and of surface brightness extraneous to the lamp and reflector seem to be of comparatively little consequence so long as the higher brilliancies of the lamps and reflectors are themselves properly taken care of. In this series of experiments we have had, including the opaque reflectors, quite wide variations in the distribution of illumination ranging from well illuminated ceilings and comparatively evenly illuminated walls and working plane for the reflectors of medium density, to the dark ceilings and upper part of the room and highly illuminated lower half of the room in case of the opaque reflectors. And, considering this work in connection with the preceding work by means of the opaque reflectors turned up and down, the translucent reflectors turned both up and down, and reflectors of the distributing and focusing types, we have had the greatest amount of light first in the upper half of the room, then in the lower, and, within limits, lanes of light have been produced; still it has been possible to get in all these cases comparatively good effects on the eye so long as no excessive brilliancies were introduced into the field of view. Again, however, we do not wish to say that this is the only factor that makes for the welfare of the eye in lighting. We wish only to call attention to its great importance.

[2] It should not be necessary to mention that the recording apparatus is screened from the observer's view while the test is being made. Before photographing, the screen was removed and the apparatus regrouped.

[3] The following points might perhaps be noted in connection with the foregoing brightness specifications. In case of the translucent reflectors installed pendant, two important items of surface brightness should be taken into account, namely, the brightness of the opening and the brightness of the outer surface of the reflector.

If a dense reflector is chosen, for example, the brightness of the opening tends to become excessively high; also its apparent or physiologic brightness is increased by induction from its dark surroundings, which effect does not register in the photometer. If on the other hand the reflector chosen transmits too much light the brightness of the outer surface of the reflector becomes too high for the comfort and welfare of the eye. For the translucent reflectors used in these tests the best results have been obtained with the reflectors of medium density as will be seen by comparing the results of Tables II and V. The reverse of this was true, it will be remembered, when the same reflectors were installed inverted. The highest brightnesses when these reflectors are installed pendant are the filament spots in the lamps. Only very small areas of these spots are visible, however, and their brightness and the brightness of the lamps differ so little from installation to installation as to be, in all probability, of relatively little consequence in a comparative study of effects on the eye.

[4] For the clinic report of the eyes of the observer whose results are given in Tables V and VI, see vol. X, p. 1128, of the TRANSACTIONS.

[5] Later, for the sake of comparison, we expect to repeat the tests for at least a part of the reflectors used in this work with clear and bowl-frosted lamps.

DISCUSSION.

J. R. CRAVATH: From the practical man's standpoint, these results seem to show us, first, that as long as we have lamp tips and filaments within the range of vision, the results will be bad where we want to reduce the glare to a minimum amount; second, aside from the lamp tip, we must look out for the opening of the reflectors. It is rather strikingly shown that not only the side of the reflector but the opening of the reflector has a very decided effect. That is something we have been prone to forget. The comparatively good showing made by what we would ordinarily call a light density open reflector demonstrates that. It should perhaps be remembered that all of these results given this year show much more eye fatigue than those shown in previous years on systems where the brightness of the brightest things within the range of vision was of a much lower order.

F. C. CALDWELL: I appreciate the large amount of work that Mr. Ferree has done on this subject, both in this and in the case of preceding papers, and the interesting results which he has obtained. It might be very valuable if we could follow this line up in the direction of more quantitative results, that is, if we could construct a series of artificial light sources having the same candlepower but successively higher brilliancies, so that a series of tests could be made which would show the maximum brilliancy that could be allowed without seriously increasing the fatigue.

R. ff. Pierce: I would like to express my appreciation of the work that Dr. Ferree has done along the line of giving the practicing engineer working data that he can use directly in the planning of installations and pre-determining their characteristics with reference to usefulness for illumination. I think that the present paper, in conjunction with previous ones gives us a very definite limit for brightness in the field of vision. If I remember correctly, the first paper that Dr. Ferree presented shows about the same amount of fatigue resulting from a semi-indirect fixture, in which the brightness was of the order of possibly 2½ or 3 cp. per square inch and a bare unshaded lamp, and this depreciation in eye efficiency, as I recall it, was about of the order obtained with reflector No. 6. I do not remember the exact figures, but judging from the slope of the curve, I believe that was about the result obtained, and his previous work also showed that semi-indirect reflectors having a brightness exceeding about one quarter of a candlepower per square inch, as I remember it, showed a considerable increase in depreciation of eye efficiency, as compared with daylight. I think, therefore, that as far as the tests have gone and the results have been presented, we may be fairly safe in saying that under the degrees of illumination used, in the neighborhood of 4 foot-candles or so, that a brightness of more than one quarter of a candlepower per square inch will produce a greater degree of fatigue than is experienced with daylight, and that any brightnesses exceeding 2 candlepowers per square inch are so exceedingly bad that we may as well have a bare unshaded lamp, as far as the efficiency of the eye is concerned. Now as to the part played by ocular discomfort, that is another matter, but as far as efficiency of the eye alone and fatigue is concerned, I think Dr. Ferree's work, which is very complete and exhaustive, justifies us in setting up that criterion of the excellence of lighting installations, that is, for illuminations is the neighborhood of 4 foot-candles, the highest permissible brightness is on the order of a quarter of a candlepower per square inch, if it is desired to obtain efficient results as far as the eye is concerned, and that all brightnesses above 2 cp. per square inch are equally bad.

George A. Hoadley: I do not care to take time to discuss this paper, because I am not competent to do it, but I do want to ex-

press my feelings that Drs. Ferree and Rand have made a most valuable contribution to the practical application of their studies to illumination. So many times the studies carried on in this direction seem to be entirely outside of the range of the ordinary human intellect. Many times it is interesting to those interested along that special line alone, but here we have a series of just as exact observations and experiments carried out in this investigation that is exactly applicable to the work of the illuminating engineer. I believe that applies to all of the work of the illuminating engineer and I am sure that we all appreciate it.

Dr. G. Rand: I should like to read some data I have just noted on the points made by Mr. Pierce concerning the magnitude of the brilliancies that has proven favorable in our tests on the eye. With the opaque reflector installed inverted, the highest brilliancy was the ceiling spot above the reflector. This measured 0.138 cp. per square inch and the lighting condition gave 8.6 per cent. loss of visual efficiency. With the opaque reflector installed pendant the best results were obtained with a deep bowl reflector having a lining with a co-efficient of reflection of 3.39 per cent., and with the same reflector having a lining with a co-efficient of reflection of 38.45 per cent. In both cases the highest brilliancies present in the field of view were the linings of the reflectors. In the former case the lining measured 0.0129 cp. per square inch, and the lighting condition gave 6.6 per cent. loss of visual efficiency. In the latter case the lining measured 0.1815 cp. per square inch and the lighting condition gave 8 per cent. loss of visual efficiency. For the translucent reflector installed inverted the best results were obtained with reflector I. Here the highest brilliancy, the reflector, measured 0.264 cp. per square inch, and the lighting condition gave 15 per cent. loss of visual efficiency. For the translucent reflector installed pendant, the best results were obtained with reflector I. The highest brilliancy, exclusive of the small amount of the lamp which was visible, was the outside of the reflector. This measured 0.66 cp. per square inch and there was 32.9 per cent. loss of visual efficiency. From these figures it would seem that we might consider that the brilliancies in the field of view should be limited to the region of 0.18 cp. per square inch if conditions most favorable to the eye are to be obtained.

The brilliancy of the semi-indirect reflector used in our earlier work, mentioned by Mr. Pierce, was 0.71 cp. per square inch.

DR. C. E. FERREE: I have been a little chary about getting away from the actual lighting conditions used, and I am not ready to say that you can fix for all light installations a limit of brightness, because you do not find the same situation in all lighting installations, and again it depends on your room; what the eye will stand in one room, it may not in another. Remember, this was all being done in a room of one size; the size of the room, the angle of presentation, for example, of the light source to the eye, is a very important thing, and I hope you will realize that in doing this work, the extensive range of the possibility of investigation and how we are simply hewing through one line as best we can, and it will take years, for example, to finish the thing, and I always have been afraid of the abstract investigation, especially when a thing as complicated as a lighting situation is concerned. I'd rather say, for this type of reflector, the pendent reflector, the inverted reflector of a certain type of design and certain size, that this will do, rather than to say there is a maximum which you can safely come up to for all types of reflectors in all situations. Now, so far as the summary of results is concerned, we have published twice, three times I think, a summary; one came out in the July number of the *Annals of Ophthalmology,* and we published a summary twice in other places. If, later, there is any opportunity of publishing a summary, I will be very glad to do it.

ELECTRIC STREET LIGHTING IN NEW YORK CITY WITH PARTICULAR REFERENCE TO THE BOROUGH OF MANHATTAN.*

BY W. T. DEMPSEY.

Before entering into a detailed description of the modern electric street lighting system of the City of New York, brief reference to the early system of lighting the streets by means of gas or naphtha lamps, and to the early electrical installations, will be of interest.

The cities of Boston and Baltimore were the first to operate gas plants in the United States; New York was the third city, and in 1823 the first company was organized and began business, supplying gas for commercial and street lighting purposes. It is somewhat doubtful just where the street gas lamps were located in New York City except that they were somewhere south of Grand Street. Ten years later, in 1833, another company was organized to operate north of Grand Street.

In 1859 there were 13,500 street lamps in service, all burning gas except a limited number of oil lamps. Several other companies were organized in various sections of the city, and in 1873 there were 18,000 gas street lamps in service; in 1879 the gas street lamps numbered 21,000. In 1877 approximately 2,000 naphtha lamps were placed in service, but their use continued for street lighting only as long as the gas was not available and in 1880 they were restricted to the lighting in parks and parkways. For this latter type of installation they were the accepted type of lighting unit until 1908, at which time their replacement by electric units began and has continued until the present time. This year will see their elimination.

The first electric street lighting occurred in New York in 1881, with an installation of twenty-three open-series arc lamps on Broadway, between 14th and 34th Streets, starting them for the first time on January 15, 1881. On May 1, 1881, an additional installation of six lamps was placed in Madison Square Park and

* A paper presented at a meeting of the New York Section of the Illuminating Engineering Society June 8, 1916.

six in Union Square Park, said to have been located on poles 160 ft. in height. This method of lighting the streets with arc lamps rapidly found favor and the total installation increased to 650 lamps in 1884, 700 lamps in 1886 and 1,330 lamps in 1888. This latter installation had, at this time, displaced a total of 6,500 gas lamps, but with the growth of the city additional gas lamps were added so that in 1881 the total number of gas lamps was 22,800.

It was not until 1892 that The New York Edison Company, operating a low tension multiple 3-wire system, entered the field of street lighting, as it had devoted the first nine years of its existence to the development of commercial incandescent lighting. At this time (1892) after considerable effort both in arc lamp and in post design, Fifth Avenue was lighted by means of posts supporting two lamps (Fig. 1). These posts, compared to those used for the support of the series arc lamps of those days, were radically different in design, and it may safely be said that they were the first real effort in America toward artistic design in electric standards for street lamps. They consisted of a cast-iron fluted base and column, surmounted by a tee section of scrolls, rosettes and leaves, comparable in general proportions and ornamentation to the posts now in use on this avenue. The arc lamps were of the open arc type, and were connected two in series across 120 volts, consuming approximately 8 amperes and 50 volts at the arc.

Following the successful lighting of this most important city thoroughfare by means of the low tension constant potential arc lamp, the development of low tension multiple are lighting proceeded vigorously, leading finally to the enclosed carbon arc lamp. The reliability and beauty of these lamps led to their standardization, and for many years they were used in increasing numbers. The steadiness of light, the reliability of operation and the possibility of incorporating this form of unit in a post of harmonious design enabled the standardization of a post equipment that was the forerunner of artistic street fixtures.

The detailed conditions controlling the location and size of illuminants in the Borough of Manhattan are determined by the Engineers of the Department of Water Supply, Gas and Electricity, who for many years have exercised jurisdiction over all

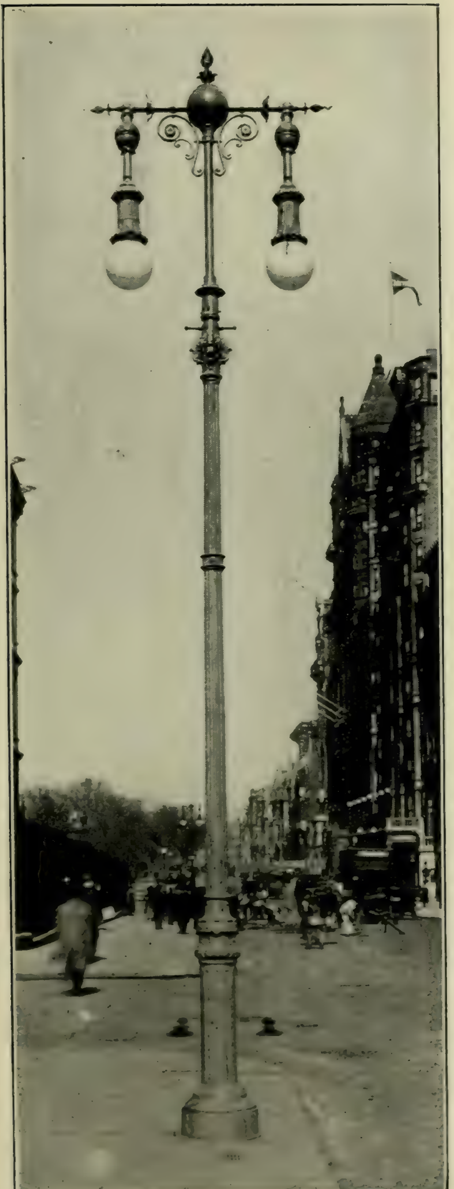


Fig. 1.—Twin post used on Fifth Avenue—400 watt lamps.

Fig. 2.—Bishop Crook Design.

Fig. 3.—Bracket design post. Steel tube shaft and applied cast and wrought iron ornamental parts.

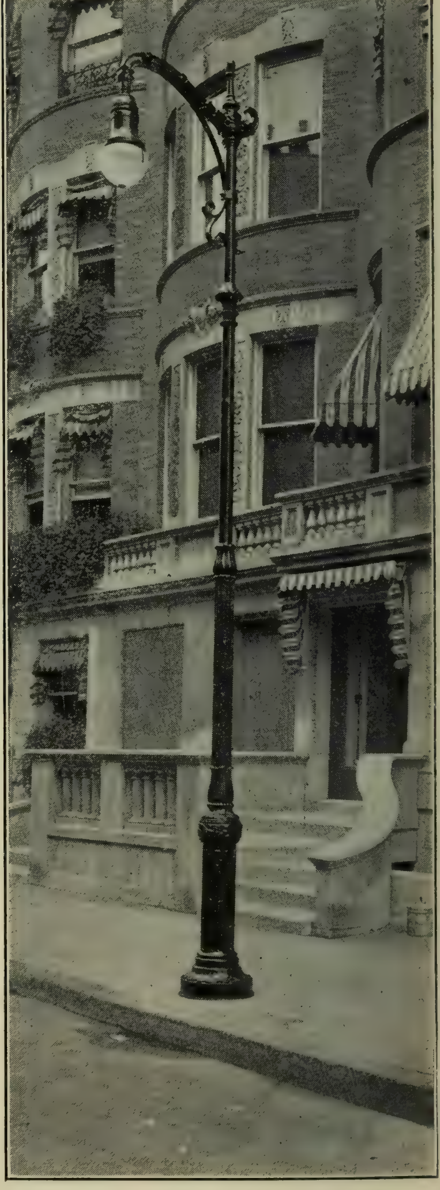


Fig. 4.—Special post designed for use in residential streets—200 watt lamps.

street lighting. In general, all important north and south thoroughfares above Houston Street are intersected at equal intervals by the east and west avenues and streets. This interval is approximately 260 feet with very little variation from this figure. The Department engineers, therefore, standardized a system for lighting with arc lamps specified to consume not less than 450 watts at the arc, whereby one such arc lamp was placed at each intersection. The gas lamps on the avenues were discontinued as they were replaced by the high intensity arc lamps. In addition to the north and south avenues, the use of the enclosed arc lamps was extended to include all of the east and west streets which contained surface car lines, particularly in the lower east side, south of Houston Street and east of the Bowery. The advent of the high-speed motor vehicle increased traffic congestion, and this was an important factor in the growth of a general demand for still better street lighting which resulted in the formation now standardized and quite common on all avenues, namely, two high candlepower units at each street intersection, placed one on either side of the avenue and diagonally opposite each other.

In building up the complete system as now installed, a great deal of study was devoted to certain thoroughfares where, for purely local reasons, installations differing more or less from the standard forms were required. Examples of such streets are: Seventh Avenue from 110th Street to the Harlem River and Broadway north of 59th Street, where advantage was taken of the center isles to locate a light source in the center of each block. These central lamps are supported on a post of the *lyre* design while in order to clear the trees on the curb line a mast arm post was designed. This latter design of post is also used on wide thoroughfares such as Tenth and Amsterdam Avenues, while the now well-known *bishop crook* design (Fig. 2) is used in many cross streets and on many important avenues, notably, Madison and Lexington Avenues and Central Park West. Within recent years a new standard *bracket* design post (Fig. 3) was adopted for use on Seventh Avenue north of 41st Street, the entire length of First Avenue, Columbus Avenue, Second Avenue south of 23rd Street, and in many isolated locations. This design is also standardized for use with series 400-candlepower lamps in the alternating current districts.

In addition to these standardized post designs used in New York, several other special designs are utilized in certain localities where local conditions require special treatment. Several of these, as well as the standard designs, are illustrated.

The present street lighting of New York in the Borough of Manhattan is by means of multiple type "C" Mazda lamps. For the avenues and principal cross streets, the lamps are mounted two at each intersecting street. The side street lighting is accomplished with specially designed posts (Fig. 4) owned by the city, which will be described later.

The advent of gas-filled incandescent lamps presented problems to the lighting companies in New York, which, no doubt, were shared by many other electricity supply companies throughout the country. The lamps found almost immediate favor with the Municipal authorities, both on account of their high efficiency and their flexibility due to the range in candlepower sizes. With their installation it was soon realized that the absence of data as to their operating characteristics required protection from the elements and ventilation, both of a nature not formerly found necessary for the vacuum lamp. The experience of those operating the lamps in service and that of the manufacturers of lamps and of lamp housings working in accord enabled the production of an efficient lighting fixture within a short time. The type of fixture designed for use for the type "C" lamp in New York has been so successful in all the details necessary for the proper and efficient operation of this type of lamp that it will be interesting to describe it in detail.

In utilizing the varying sizes of multiple lamps all car-line streets, or wide avenues, are lighted by means of the 400-watt lamp (Fig. 7); the 300-watt lamp is used on avenues where traffic is relatively light. Generally speaking, the mounting height of 300-watt lamps will approximate 19 to 20 feet above grade, while the 200-watt lamps on residential streets are 16 ft. 6 in. above grade. A special installation on Park Avenue between 60th and 96th Streets where the 100-watt lamps are 14 ft. 6 in. above grade, while the same lamps in all parks is 10 ft. above grade. All lamps of 200 watts and over are enclosed with diffusing globes of a single glass mixture with less than 15 per cent. absorption. The 100-watt lamps are equipped with clear globes. The decision to

Fig. 5.—Method used to locate light source under low hanging elevated railway structures. Note six light sources in view.

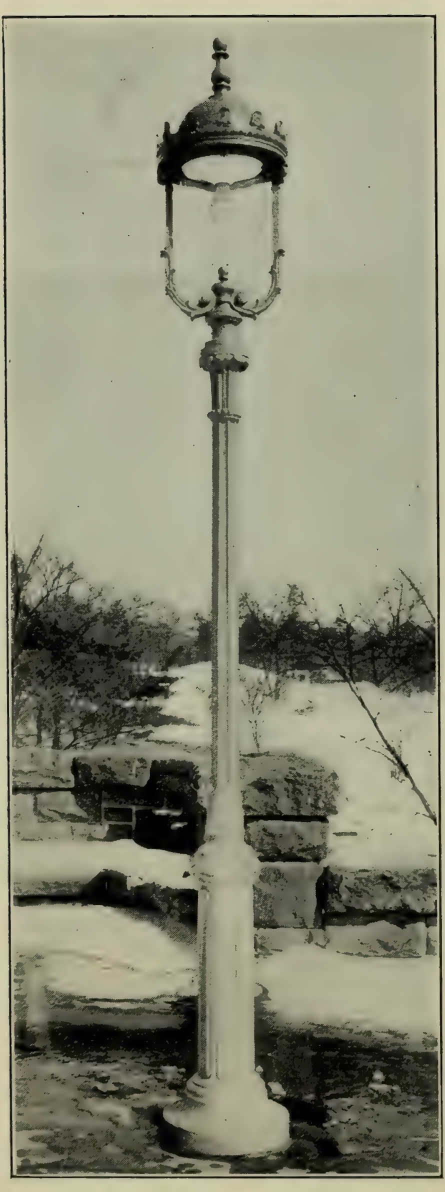


Fig. 6.—Designed for use in Parks—100 watt lamps.

Fig. 7.—Night view—Fifth Avenue looking north from 27th Street—400 watt lamps, two to a post.

Fig. 8.—Special truck and rigging used in construction of street lamp posts.

utilize these particular sizes on the classes of streets described was arrived at only after thorough and exhaustive tests had been made to determine the lamps suitable for the local conditions. The improvement secured in illumination and candlepower will be illustrated later.

For reasons already stated the engineers of the Department of Water Supply, Gas and Electricity had limited their efforts toward improved street lighting to the important streets or avenues, permitting the purely residential streets to retain the Welsbach mantle gas installations, realizing, however, that there was a marked difference in illumination as compared to the avenues. The type "C" lamp provided a solution of this problem, and they hastened to utilize it in replacing the Welsbach lamp. After many extensive tests, many of which were conducted in the field, and were the deciding factor, the 200-watt lamp, supported on a specially designed post, was standardized for use in residential streets.

While it has been stated several times that various lamp sizes and post designs have been standardized for use on certain streets and avenues, there are still many conditions where special equipments (Fig. 5) have been installed to meet the local conditions; for instance, beneath elevated railway structures in Greenwich, Allen and Division Streets, in Park Avenue between 102nd and 111th Streets, where the railroad viaduct occupies the center of the roadway, and also in streets where traffic conditions do not permit post installation, or streets where lack of room on the sidewalk prevents the installation of posts.

You will remember the statement regarding the use of naphtha lamps. It was in 1908 that the lighting companies in New York City undertook the work of electrically lighting the parks. After an extensive series of tests the 100-watt vacuum lamp was standardized for this purpose, and this lamp is used in Central Park, Riverside, Morningside and St. Nicholas Parks. On driveways the posts are located approximately 80 ft. apart and staggered on either side of the roadway, while in other localities they are placed to meet the local conditions.

After thorough investigation of the several methods used in furnishing underground electrical supply it was finally decided to use a duplex and triplex steel banded, lead covered, rubber in-

sulated cable. Several features in favor of this cable led to its use. It was to be used in localities where it could be laid under grass plots, unpaved or unsurfaced roads and where it would not be subjected to undue mechanical stress; the vehicular traffic would be light and its flexibility would permit detours around obstructions and prevent the destruction of the roots of trees, etc., which would be encountered. The cable was placed about 12 in. to 15 in. below grade in a trough, spade wide, thereby reducing excavating to a minimum. All ends were brought up into the post, permitting convenient testing points, and also facilitating rapid installation. Finally, it was used also as submarine cable, taking the shortest route across the several park lakes.

All of the park circuits are multiple, the various individual circuits being controlled at certain points. Central Park has an installation of approximately 1,100 posts (Fig. 6) and is controlled by 89 master switching points, the number of lamps on a circuit varies between 3 and 75 in a group.

Riverside Park and several sections of Riverside Drive are supplied and lighted in the same manner, with a total of 288 lamps. This type of installation is also used in St. Nicholas and Morningside Parks, with 25 and 86 lamps respectively.

The following horizontal illumination values are applicable to the present installation on Seventh Avenue north of 110th Street, measurements being made 4 ft. 8 in. above grade. The lamps are 400-watt, 22 ft. above grade along the curb while the center lamp is 20 ft. above grade.

Foot-candles—maximum	0.96
minimum	0.021
average	0.135

Madison Avenue—lamps 18 ft. 6 in. above grade:

	300 Watt	400 Watt
Foot-candles—maximum	0.75	1.04
minimum	0.0101	0.015
average	0.135	0.185

In residential streets the following results have been found, the tests were made in 68th Street between Central Park West and Columbus Avenue.

There are three 200-watt lamps in this street, mounted on posts 16 ft. 6 in. above grade.

Fig. 9.—Special truck and rigging used in construction of street lamp posts.

Fig. 10.—Electrically operated tower used to maintain and construct street lamp posts. Vehicle motor circuit is opened automatically when tower is raised.

Foot-candles—maximum	....	0.347
minimum	....	0.0102
average	....	0.068

The system of street lighting described in this paper refers to the lamps served in the Borough of Manhattan by both The New York Edison Company and the United Electric Light and Power Company.

Aside from the simplicity of operation of the multiple and series gas-filled lamps, their particular significance as a factor in street lighting lies in the flexibility obtained from the many available sizes, as compared with the relatively small range of intensity obtained with carbon-arc lamps. With the wide range of candlepower to select from, the illuminating engineer is enabled to choose a light source to meet any conditions encountered, from the small lamp required simply to mark the line of an infrequently traveled country road, to the largest units used to illuminate congested street intersections.

In the construction and maintenance of street lamp posts, special types of automobile trucks are used. The tower of one type (Fig. 10) is raised and lowered by a motor supplied from the vehicle battery. The workman remains in the cage while the tower is in use. A heavier type of motor truck and rigging is shown in Fig. 8 and Fig. 9.

The following tabulation illustrates the extent to which the engineers of the Department of Water Supply, Gas and Electricity have utilized the type "C" lamp in their efforts to improve the street lighting conditions throughout Greater New York in this district:

JANUARY 1, 1916.

Size	Manhattan	Bronx	Brooklyn	Queens	Richmond	Total
200-watt "C"	2,558	16	262	—	71	2,907
300-watt "C"	4,477	23	1,746	—	—	6,246
400-watt "C"	3,531	—	1,904	—	—	5,435
500-watt "C"	69	—	—	—	—	69
750-watt "C"	34	—	—	—	—	34
100-watt "B"	2,948	371	2,064	18	—	5,401
400-cp. "C"	45	2,388	2,663	1,814	—	6,910
100-cp. "C"	—	8,312	364	15,177	4,564	28,417
250-cp. "C"	—	29	—	—	509	538
600-cp. "C"	—	4	—	53	—	57
Total	13,662	11,143	9,003	17,062	5,144	56,014

THE LAWS OF REFLECTION AND TRANSMISSION OF LIGHT.*

BY THOMAS W. ROLPH.

Certain of the laws of reflection and transmission of light are well-known and widely utilized in the design of lighting equipment. There are other laws which, although equally important, are much less well-known and too often entirely neglected in design. It is an unfortunate fact that many forms of lighting equipment which are recommended on the basis of engineering merit, have been designed without the application of the fundamental laws which govern their performance, and in some cases have been designed by the application of laws which do not apply to the reflecting material used. It often happens too, that the users of lighting equipment so little appreciate the performance which they ought to expect from the equipment they purchase, that such units receive favor, which they are not entitled to. In the long run they are, of course, destined to failure; but it would be of advantage to manufacturers and users alike, if there were a better general understanding of the methods by which light is controlled by various materials. In this paper an endeavor is made to state and explain those laws which fundamentally affect the design of lighting equipment. Much of the material included here has already appeared in the TRANSACTIONS of this Society, and in technical publications.[1] The author believes, however, that there has not been any general exposition of these laws or any previous attempt to group them and show their interrelationship. Some of the terms employed in this paper are new, but the majority of them have already been used by many engineers and, as they are comparatively simple and are descriptive of the phenomena referred to, they would seem to merit general usage.

* A paper presented before the Pittsburgh Section of the Illuminating Engineering Society, Pittsburgh, Pa., Jan. 21, 1916.

The Illuminating Engineering Society is not responsible for the statements or opinions advanced by contributors.

[1] Some of these references are:
Radiation, Light and Illumination, C.P. Steinmetz. pp. 221-225.
Reflecting Media—Authur J. Sweet, Railway Electrical Engineer, June, 1913.
Metal Reflectors for Industrial Lighting, Thomas W. Rolph, I. E. S. June, 1913.

The laws of reflection and transmission of light may be conveniently classified as primary laws and secondary laws. Under this classification, the primary laws are those which refer to the action of a medium on a single ray[1] of incident light. The secondary laws are those which refer to the action of a medium on parallel incident light rays.

PRIMARY LAWS.

The primary laws will be touched on only briefly here, as they will be found fully explained in any text-book of physics. They include principally:

1. The law of reflection, that the angle of the reflected light is equal to the angle of the incident light.

2. The law of refraction, that the sine of the angle of refraction of a light ray passing from one medium into another medium is equal to the sine of the angle of incidence multiplied by a factor which is determined by the relative refractive indices, or the relative optical densities of the two media.

Fig. 1 illustrates the primary law of reflection, that the angle of incidence is equal to the angle of reflection. This law is expressed by the formula:

$$i = r$$

i being the angle which the incident light ray makes with the normal to the reflecting surface, and r the angle which the reflected light ray makes with the same normal.

The law of refraction is illustrated in Fig. 2. It is expressed by the formula:

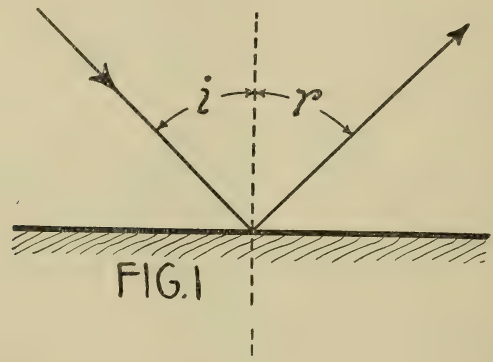
$$\sin r = \sin i \frac{n_1}{n_2}$$

in which i is the angle which the incident light ray makes with the normal to the surface and r is the angle which the refracted light ray makes with the normal, while n_1 is the refractive index of the first medium and n_2 the refractive index of the second medium. When the first medium is air, whose refractive index is taken as 1.00 (approximately) the formula becomes

$$\sin r = \frac{\sin i}{n}$$

[1] While it is difficult to form a conception of a single light-ray consistent with the wave theory of light, it is convenient and will lead to no erroneous conclusions, to consider a single light-ray as the light proceeding along a straight line having no dimensions except length.

n being the refractive index of the medium into which the light passes from the air.



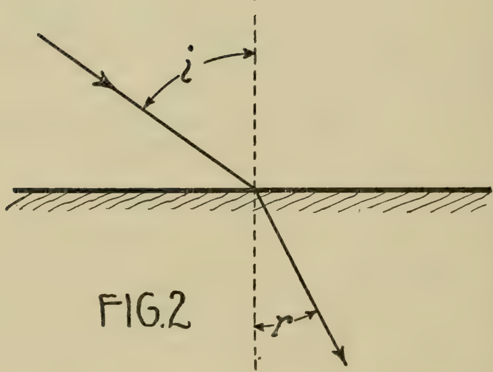


Fig. 1. Illustrating the primary law of reflection.
Fig. 2.—Illustrating the primary law of refraction.

These two laws hold absolutely for a ray of light striking or entering a medium. When a pencil of parallel light rays strikes or enters a medium, however, the result may be quite different, as the pencil may be broken up and scattered in all directions, apparently not following these laws. However, each individual light ray accurately follows the above laws and the scattering or other effect obtained is due to differences between different parts of the medium. These differences are such that a set of laws may be formulated, definitely governing the action of the various classes of media upon a pencil of light-rays. These laws are what are termed herein the secondary laws of reflection.

THE SECONDARY LAWS OF REFLECTION.

These laws are three in number:

1. The law of regular or specular reflection.
2. The law of spread reflection.
3. The law of diffuse reflection.

Fig. 3 shows the operation of these laws. Fig. 3*a* illustrates the law of specular or regular reflection. This is the same for a pencil of light-rays as for a single ray (Fig. 1). The angle of incidence is equal to the angle of reflection, and all of the reflected light travels in the same direction. Fig. 3*b* illustrates the law of spread reflection. The maximum intensity of the reflected

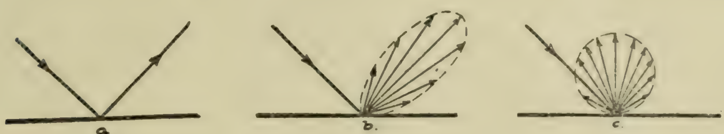


FIG. 3

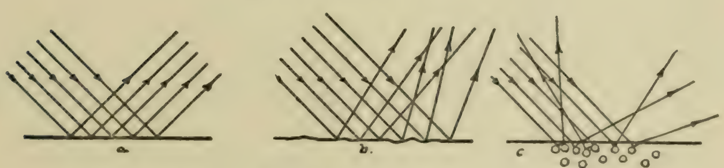


FIG. 4

Fig. 3.—Illustrating the three secondary laws of reflection. *a*—Regular or specular reflection. *b*—Spread reflection. *c*—Diffuse reflection.

Fig. 4.—Magnified view illustrating the action of various media reflecting light in accordance with the secondary laws of reflection. *a*—Regular or specular reflection. *b*—Irregular reflection producing spread reflection. *c*—Sub-surface reflection producing diffuse reflection.

light is in the same direction as in regular reflection, but a portion of the light is spread from this direct path, so that the net result is a slightly spreading beam of light of the same general direction as in the case of regular or specular reflection. The dotted line surrounding the reflected light-rays is what might be termed the photometric curve of a small portion of the surface. This is roughly in the form of an ellipse, but the shape is variable, depending upon the character of the surface. Fig. 3*c* illustrates the law of diffuse reflection. With diffuse reflection, the

distribution of the reflected light is entirely independent of the angle at which the light strikes the surface. No matter what this angle may be, the maximum intensity of the light reflected, is normal to the surface, and the light is spread throughout an angle of 180°. The photometric curve of the light reflected from a small portion of the surface is represented by the dotted line in Fig. 3*c*. This curve is always a circle, or considering the light reflected in all planes, a sphere. This spherical distribution obtained with diffusely reflected light is determined by what is known as the cosine law, which states that the intensity of the reflected light at any angle from the normal to the surface is proportional to the cosine of the angle.

Fig. 4 shows the manner in which different surfaces act upon light to produce regular, spread and diffuse reflection. In this figure the surfaces are greatly magnified, showing the action of the individual light-rays which make up the pencil. As shown in Fig. 4*a* specular or regular reflection is obtained from a perfectly smooth surface, so that each light-ray in the pencil of light is reflected in the same direction. As shown in Fig. 4*b* spread reflection is produced by irregular reflection of the individual light-rays. Irregular reflection is obtained from any rough or mat surface. Each individual ray of light follows the primary law that the angle of incidence is equal to the angle of reflection, but the rough character of the surface means that the light is reflected in all directions, although the main portion of it is close to the direction of regular reflection. The net result for a pencil of rays is the spread reflection illustrated in Fig. 3*b*. Measurements of results actually obtained are shown in Fig. 5. The curves in this figure are the photometric curves of a 10-in. flat aluminum finished plate with parallel light-rays striking the plate at the angles indicated. The candlepower measurements were made at a distance of 10 ft. from the plate by the use of a standard photometer. It will be seen that the results obtained correspond closely to the theoretical distribution of spread reflection.

Regular reflection and spread reflection are obtained by reflection from the surfaces of reflecting materials. Diffuse reflection, as ordinarily obtained, however, is produced by reflection from particles beneath the surface. Fig. 4*c* illustrates this sub-surface

reflection. The individual light-rays penetrate the surface and are reflected back and forth from the minute articles beneath the surface, emerging in all directions. The net result for a pencil of light-rays is the cosine law distribution of Fig. 3*c*. Of course, a small part of the light is reflected from the surface itself, as will be touched on later, but the greatest portion enters

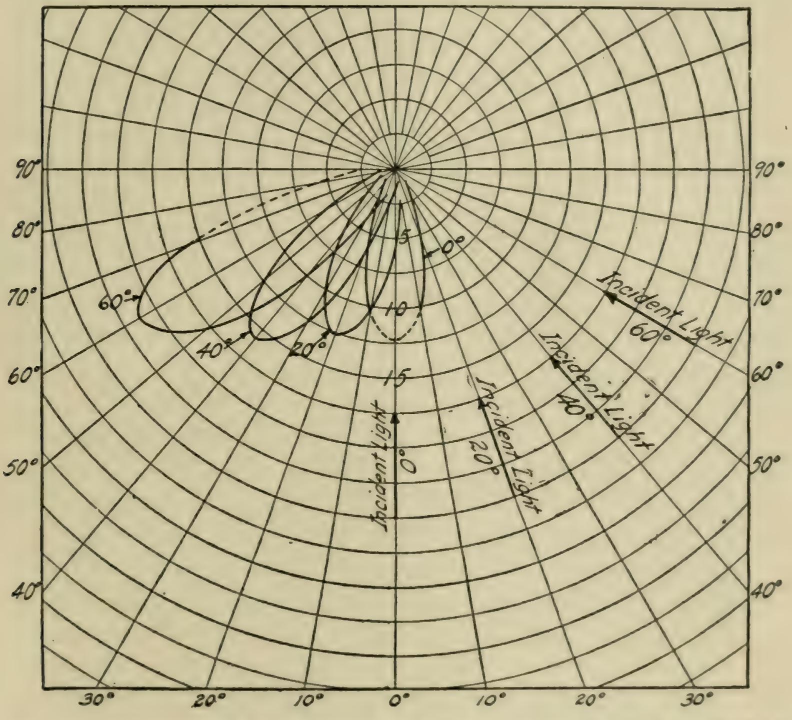


Fig. 5.—Photometric test of a mat aluminum surface giving spread reflection, with light incident at various angles.

the surface and emerges perfectly diffused. It seems probable that diffuse reflection is nearly always produced by sub-surface reflection. Opal glass, porcelain enamel, and paint enamel are well-known examples of this. Blotting paper gives diffuse reflection and at first sight it might appear that the diffusion is produced by surface reflection. However, it is only necessary to observe the amount of light actually transmitted by an ordinary piece of blotting paper to be convinced that the greater part of

the light penetrates the surface to an appreciable depth. The fibrous nature of the material means that a large part of the light is probably reflected back and forth close to the surface before emerging. The paint finishes used for ceilings, walls and other interior decoration also act by diffuse reflection, and the light is reflected from beneath the surface. This is evidenced by the fact that when these finishes are glazed so that surface re-

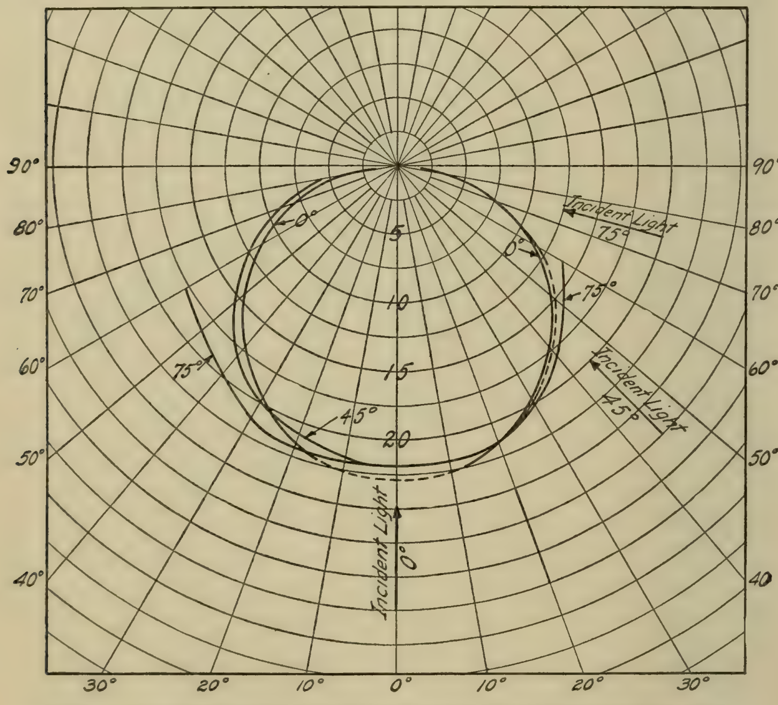


Fig. 6.—Photometric test of a kalsomine surface giving diffuse reflection, with light incident at various angles.

flection is regular or specular, the greater part of the light is still diffusely reflected. Photometric measurements[3] show the diffuse character of this reflected light and observation indicates the same, for if the greater part of the light were reflected from the glazed surface, the effect would be the same as obtained with a mirror. This effect is never obtained with these finishes unless the material is very dark, absorbing the light which would other-

[3] Some reflecting properties of painted interior walls, Claude W. Jordan—Trans. I. E. S., vol. VII, p. 529.

wise be reflected diffusely from beneath the surface. Furthermore, if a colored wall surface is observed in the direction to catch the high light, caused by regular or spread reflection of a light-source, it will be observed that this high light is the color of the light-source and not the color of the wall. Since this is surface reflection, the diffuse reflection showing the color of the wall must be sub-surface reflection. Fig. 6 shows the distribution obtained from a kalsomine surface with varying angles of incidence. These results are obtained by actual measurements of candle-power from a 10-in. plate, with parallel light incident, as in Fig. 5. The surface, while not glazed, was a smooth mat surface, of approximately the same degree of smoothness as the surface used in Fig. 5, thus indicating the large amount of sub-surface reflection with kalsomine paint.

Since regular reflection and spread reflection are ordinarily obtained by reflection from the surface of a material, and diffuse reflection from beneath the surface, it is possible to obtain from the same medium, combinations of regular and diffuse, and spread and diffuse reflection. Furthermore, since the reflecting material often has two surfaces, as the inside and outside of a reflector, and both surfaces may be effective, it is possible to obtain a combination of specular and spread reflection from the same material. Fig. 7 illustrates the three possible combinations. Fig. *7a* shows the combination of specular reflection and diffuse reflection. In practice this is the most important combination, as this is the reflection obtained from opal glass, porcelain enamel and paint enamel surfaces. The specular reflection is produced by the smooth surface of the material, while the diffusely reflected light, which is the greatest part, comes from beneath the surface. The specularly reflected light, while appearing large in the diagram, is in reality comparatively unimportant, as in quantity it amounts to a small percentage of the total light reflected. The amount of surface reflection is determined by the refractive index[4] of the material. With glass in common use (refractive index 1.5) the surface reflection amounts to less than

[4] The quantity of light reflected from a surface is determined by the Fresnel law of reflection.

$$R = \frac{\sin^2(i-r)}{2\sin^2(i+r)} + \frac{\tan^2(i-r)}{2\tan^2(i+r)}$$

in which R is the percentage of light reflected, i is the angle of incidence and r is the angle of refraction.

5 per cent. for angles of incidence from the normal out to 45 deg. At 60 deg. incidence, the surface reflection is about 9 per cent.; at 75 deg., 25 per cent.; at 85 deg., 61 per cent.; at 88 deg., 90 per cent.; and of course, 100 per cent. at grazing incidence. Test on a clear (crystal) glass deep bowl shade showed 8 per

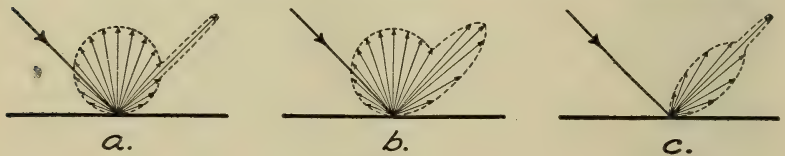


FIG. 7

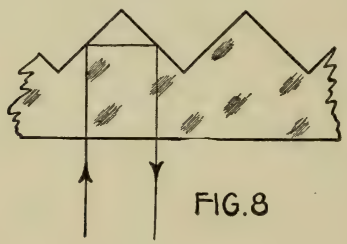


FIG. 8

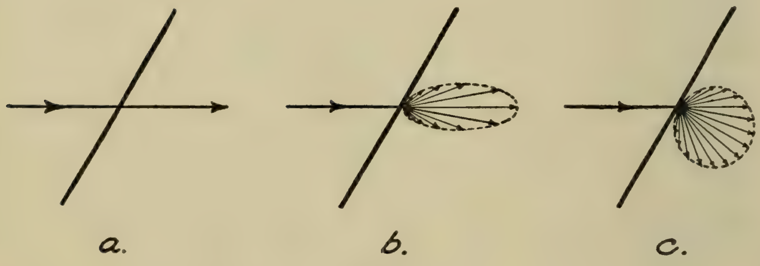


FIG. 9

Fig. 7.—Combination of two kinds of reflection from the same material. *a*—Specular and diffuse. *b*—Spread and diffuse. *c*—Specular and spread.

Fig. 8.—Horizontal cross-section of a portion of a prismatic reflector.

Fig. 9.—Illustrating the Three Secondary Laws of Transmission. *a*—Direct transmission. *b*—Spread transmissson. *c*—Diffuse transmission.

cent. of the incident light reflected, considering both surfaces of the glass.[5] With a shallow clear glass reflector, the reflection would be a little greater, but probably rarely more than 10 per cent. of the incident light. This means that only rarely is more than 5 per cent. of the incident light reflected from the inner

[5] Reflecting Media, Arthur J. Sweet—Ry. Elec. Eng., Jan. 1913.

surface of a reflector. This holds for opal glass and enamel surfaces, as well as for clear glass, as the refractive indices are not greatly different. In the past, the importance of surface reflection has been greatly exaggerated in the minds of many. It is well to note, therefore, that the amount of light reflected from the surface of clear and opal glass and finishes such as porcelain and paint enamel is practically negligible in most problems pertaining to illumination. An error which many manufacturers have fallen into, is that of showing, in their advertising matter, the rays of light, reflected from an opal glass, paint enamel or porcelain enamel surface, in accordance with the law of regular reflection. As a matter of fact, probably 95 per cent. of the reflected light is diffusely reflected. If the surface is depolished instead of smooth, the percentage of light diffusely reflected is still about the same, as noted below.

Fig. *7b* shows the combination of spread reflection and diffuse reflection. This combination is obtained from a diffusely reflecting material such as opal or porcelain enamel, when the surface is etched or roughed. Here again the maximum portion of the light is the diffusely reflected part, reflected from beneath the surface. The surface reflection is about the same in amount as with the combination of regular and diffuse reflection. This is indicated by tests showing the same percentage of light reflected from deep bowl clear glass and roughed glass shades of the same shape and size.[6]

Fig. *7c* shows the combination of specular reflection and spread reflection. This can only be obtained by reflection from two surfaces of the material, such as the inside and the outside of a piece of glass. Crystal glass roughed outside, gives this combination. The specular reflection is surface reflection obtained from the inside of the glass and the spread reflection results from light passing through the inner surface and reflected from the outer surface. Practically, this combination of specular and spread reflection is unimportant, as the materials which will produce it transmit much more light than they reflect and are not good materials to use for reflectors.

It has been pointed out that specular or regular reflection and diffuse reflection follow exact mathematical laws. Spread re-

[6] Reflecting Media, Arthur J. Sweet, Ry. Elec. Eng., Jan. 1913.

flection does not follow a mathematical law. It is obvious that with varying degrees of roughness of the surface, a varying degree of spread of the light will be obtained. It is probable that there is no surface, however, which will give such a spread of light as to produce perfectly diffuse reflection at varying angles of incidence. The spread reflecting surfaces which are encountered in practice do not, as a rule, give a great spread to the light. Fig. 5 is typical of the actual results obtained with surfaces which are widely used for opaque reflectors. Of course, any number of freak spread distributions are possible, but for practical purposes, these need not be considered. Spread reflection should never be considered as a combination of specular and diffuse reflection. These two cannot be combined in any proportions which will give spread reflection.

APPLICATIONS OF THE SECONDARY LAWS OF REFLECTION.

In practical illumination work, treating of the reflecting qualities of ceiling, walls, and interior finishes, and in practical design work, treating of the reflecting qualities of materials used in lighting equipment, it is not necessary to consider more than the following varieties of reflections:

Specular reflection; obtained from mirrored glass, prismatic glass and polished metallic surfaces.

Spread reflection; obtained from etched prismatic glass and rough metallic surfaces, Fig. 5 being typical.

Diffuse reflection, usually slightly modified by a small specular or spread element; obtained from opal glass, porcelain enamel, paint enamel, and ordinary ceiling and wall finishes.

While other combinations may be obtained and many varieties of spread reflection may be obtained, such combinations and varieties are relatively unimportant.

It is apparent from the nature of these types of reflection of light that regular or specular reflection will control light most accurately. A perfect mirror or polished metal surface is absolute in the control of the light which it reflects. A small portion of the light enters the surface, but the remainder is reflected in directions which can be governed accurately. This type of reflecting material is useful for searchlights, headlights, etc.,

where light is to be projected a great distance and therefore must be controlled with extreme accuracy. Such material, however, is not usually suitable for reflectors for general lighting on account of the resulting streaks or striations in the illumination. Due to the exactness with which the reflector controls light, the actual image of portions of the filament are reproduced on the surface illuminated. Some years ago, it was not uncommon to see reflectors with a polished aluminum interior surface, used for local lighting. As this undesirable characteristic of the illumination obtained from such reflectors has been realized, however, their use has decreased and they are rarely seen at the present time.

Spread reflection while less accurate in the control of light, still exerts a considerable degree of control, and surfaces giving spread reflection are of great practical importance. It is possible with spread reflecting surfaces, to design shapes of reflectors which will give all of the light distributions most widely useful for interior illumination. Furthermore, the streaked illumination which characterizes reflectors with specular surfaces and limits their usefulness, is entirely absent when reflectors acting by a spread reflection are used. With diffuse reflection, however, control of light is difficult. It is possible to re-direct light in a general direction, but when the maximum intensity of light is reflected in any particular direction, some of the reflected light is obtained nearly 90 deg. each way from this direction as shown in Fig. 3. This means that only a limited control of the light is possible. Diffuse reflectors may be designed to give a general downward distribution of light, but extreme distributions of light, such as the focusing distribution are impossible with a diffusely reflecting medium.

In view of the above consideration it is well to consider the field of usefulness of materials commonly employed for reflectors.

Considering first the media which are translucent, prismatic glass stands out as important from the engineering standpoint. The usual type of prismatic reflector is smooth inside with prisms on the outside. Fig. 8 is a cross section in a horizontal plane of a portion of such a reflector. Each ray of light passes through the inner surface with a small amount reflected from the surface,

and is specularly reflected twice from the outer surface and then passes back through the inner surface. This is specular reflection, but due to the fact that most of the light is reflected or refracted at least four times, slight variations in the glass are magnified in effect and the net result is an extremely slight spreading from the direct path of specular reflection. This results in one of the important advantages of prismatic glass, namely, that an extremely high degree of light control can be obtained (nearly as great as with polished metal or mirrored glass), yet the streaked illumination which is characteristic of polished surfaces, is almost entirely absent with prismatic glass. While prismatic glass is classified as a specular reflecting material, the control of light is not quite as accurate as can be obtained with most specular materials. When the inner surface of a prismatic reflector is etched or roughed (velvet finish, as it is called), the material partakes of the reflecting characteristic of roughed crystal glass and gives spread reflection. At the present time, velvet finished prismatic reflectors are the only translucent reflectors in widespread use, acting by spread reflection.

Etched or roughed crystal glass gives spread reflection, but is not practical as a reflector on account of the great amount of light transmitted. While etched or roughed glass shades are used in great numbers, they cannot be recommended from the engineering standpoint.

Opal reflectors act by diffuse reflection and as pointed out above, this means that they do not accurately control the light reflected. It must not be supposed, however, that these reflectors have not a decided field of usefulness. While extreme distributions of light, such as the focusing distribution, cannot be obtained, general downward distributions are readily secured. Opal reflectors can be designed to give the intensive distribution and also distributions considerably wider than the intensive, although not as wide as the theoretical extensive curve. It so happens that distribution of light between the extensive and intensive are the most widely useful distributions for interior lighting. Consequently opal reflectors are satisfactory for a large proportion of the interior lighting propositions requiring translucent reflectors.

Passing on the opaque reflectors, mirrored glass is the only

type of opaque glass reflector in general use. As pointed out above, mirrored glass in its ordinary form is not suitable for reflectors for interior lighting. However, by the use of corrugations in the glass, the objectionable striations in an illuminated surface may be eliminated and the net result is some form of spread reflection, probably quite different from that illustrated in Fig. 5, but nevertheless possessing the important advantages of spread reflection. Mirrored glass, in this construction, is suitable for opaque reflectors, and is used to a considerable extent.

Metal reflectors are usually finished with an applied finish, although in some reflectors the body of the reflector itself is the reflecting surface. It seems to be a general rule that metallic finishes, either natural or applied, act by surface reflection, specular or spread, while non-metallic finishes act by sub-surface reflection, which is diffuse. Polished nickel is a finish widely used when specular reflection is desired, as in headlights. The illumination obtained from these specular reflectors shows striations or streaks of light, but this undesirable characteristic is more than compensated for by the accurate control of light obtained, permitting projection to a great distance.

Applied aluminum paint finish is widely used as a spread reflecting surface (see Fig. 5). Porcelain enamel is a widely used diffusely reflecting surface. In their reflecting characteristics, aluminum finish and porcelain enamel hold the same relative position among opaque reflectors as velvet finished prismatic glass and opal glass hold among the translucent reflectors. Aluminum finish reflectors give excellent extensive, intensive and focusing distributions of light. Porcelain enamel reflectors give readily the intensive distribution and fair approximations to the extensive distribution, which are the distributions most widely useful, as pointed out in the discussion of opal reflectors. Of course, in comparing the two finishes, there are other considerations such as cost and durability, which have no place in the present discussion.

Paint enamel and other non-metallic paint finishes, while differing in efficiency and other characteristics nearly all give diffuse reflection of light, and consequently the distribution results obtainable with them are about the same as with porcelain enamel.

SECONDARY LAWS OF TRANSMISSION OF LIGHT.

When a single ray of light passes through a medium, its path is governed by the primary law of refraction acting at surfaces and the primary law of reflection, acting at surfaces and obstructions encountered. When a small pencil of light-rays passes through a medium, however, the resultant emerging light is determined by secondary laws depending on the nature of the medium. These secondary laws are exactly analogous to the secondary laws of reflection. As in reflection we have the secondary laws of regular, spread and diffuse reflection, so in transmission we have:

1. The law of direct transmission.
2. The law of spread transmission.
3. The law of diffuse transmission.

These three laws of transmission are illustrated in Fig. 9. Direct transmission is illustrated in Fig. 9*a*. The light passes through the medium unchanged in direction of any part of the pencil of rays, except for a slight displacement caused by the refraction at each surface. There is a certain loss of light by reflection at the two surfaces and by absorption in the medium, but this affects only a small part of the light. Direct transmission is obtained with clear glass.

Spread transmission is illustrated in Fig. 9*b*. The largest part of the transmitted light is in the direction of direct transmission. The rays are slightly spread from the direct path, however, as in spread reflection. The photometric curve from a small part of the surface is roughly in the form of an ellipse. As in spread reflection, the shape of this curve is variable, the ellipse being the most common form and the most important practically.

Diffuse transmission is illustrated in Fig. 9*c*. The light in passing through the medium is perfectly diffused, *i. e.*, is broken up and reflected and refracted in all directions, so that in leaving the glass it emerges in accordance with the cosine law. In other words, the maximum candlepower of the transmitted light is in the direction normal to the surface, and the light is spread through an angle of 180 deg. The photometric distribution from a very small portion of the outer surface of the glass is a sphere tangent to the surface. The cosine law which governs the emis-

sion of light from such a medium is the same in its operation as in governing the emission of light from an incandescent body.

a. b. c.

FIG. 10

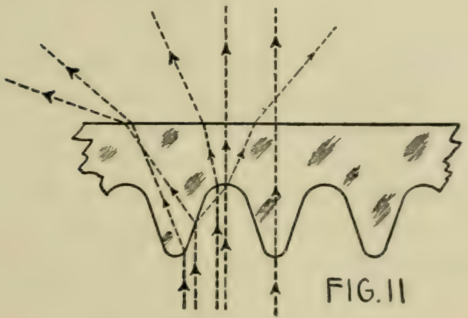
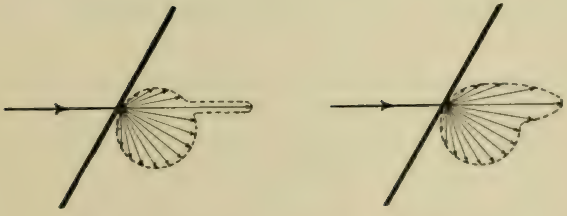


FIG. 11



a. b.

FIG. 12

Fig. 10.—Magnified view illustrating the action of various media transmitting light in accordance with the Secondary Laws of Transmission. *a*—Direct transmission. *b*—Spread transmission produced by refraction. *c*—Diffuse transmission produced by reflection and refraction.

Fig. 11.—Diffuse transmission in one plane, produced by Holophane prismatic construction.

Fig. 12.—Combinations of two kinds of transmission from the same material. *a*—Direct and diffuse. *b*—Spread and diffuse.

Fig. 10 shows how various media act on the incident light rays in producing these three different kinds of reflection. In

this figure, the medium is highly magnified, showing the paths of individual light-rays.

Direct transmission, as illustrated in Fig. 10*a*, is produced when a medium is clear, allowing the unobstructed passage of the light rays except for the small reflection loss at the two surfaces and absorption in the material itself. There is a bending of the light rays by refraction when they enter the glass at any angle other than the normal, and a bending when they leave the glass. These two deviations from the direct path, however, exactly compensate in angular change (when the two surfaces of the medium are parallel) so that there is no change in the direction of the light, other than a slight displacement from its former path.

Spread transmission, as illustrated in Fig. 10*b*, is obtained with material having an irregular surface, which may be either the inner or the outer surface. The light is refracted at the surface and on account of the various angles of incidence, the refractions bend the light-rays in various directions. The greatest intensity of the emerging light is in the same direction as in direct transmission and the greater part of the light is spread only slightly from this direction, but a small amount is spread at wide angles. The net effect is a spreading of the light, most commonly in the form of the elliptical distribution shown in Fig. 9*b*.

Diffuse transmission, Fig. 10*c*, is ordinarily produced by the interference of particles or bubbles in the glass itself. These cause reflection and refraction back and forth within the glass, and break up the light-rays, sending them in all directions. The figure shows the probable paths of typical light rays, although much of the light is no doubt refracted or reflected many times. The emergence of the light is in accordance with the cosine law. The only difference between diffuse reflection and diffuse transmission is in the side of the glass from which the light emerges. In both cases the light is broken up in all directions after entering the glass; in diffuse reflection it emerges on the entering side, while in diffuse transmission it emerges on the opposite side. It might be thought that a particularly rough surface would also break up the light so thoroughly that it would be scattered in all directions within the glass. This is undoubtedly possible, but is

probably never obtained in any mat surface which is used for lighting equipment. Such surfaces have been calculated, as for example, the interior prismatic surface of the Holophane globe. This is illustrated in Fig. 11. The prisms are so calculated that they will produce perfect diffusion of the light in one plane, by refraction and surface reflection, at the interior surface, and refraction at the outer surface. This construction is effective in producing the diffusion it was designed to produce. The diffusion, however, is in one plane only. Thus, when the prisms are vertical, as they usually are, the light is diffused only in horizontal directions. In the other plane, the light is not diffused at all, but is usually acted upon by re-directing prisms on the outside of the globe. Such a calculated surface, to obtain perfect diffusion in all planes, would have to consist of circular projections or dots on the glass, rather than prisms.

There are two possible combinations of the three kinds of transmitted light. Direct and spread transmission, since they occur at the surface of the material may each be combined with diffuse transmission which is produced within the material. The combination of direct and spread transmission cannot be obtained with a single medium.

When the two surfaces of the medium are smooth and the particles within not sufficient to diffuse all the light, a combination of direct transmission and diffuse transmission is obtained. It might be thought that in such a case the particles within would partially diffuse all of the light instead of completely diffusing a part of the light, but the latter is the case. A part of the light passes through unchanged in direction and the remainder is perfectly diffused. The character of the transmitted light is illustrated in Fig. 12*a*. If the medium is such as to produce this combination and the surface of the glass is rough instead of smooth, then the directly transmitted light will be spread and the result will be a combination of spread transmission and diffuse transmission. This is illustrated in Fig. 12*b*.

It is interesting to determine just how these laws of transmission of light operate in producing the different appearances of lighted globes. Fig. 13 has been drawn to show this operation of the laws. Fig. 13*a* shows a globe giving direct transmission of light. The eye at a distance from the globe, receives no light

which appears to come from the globe itself, but only the direct light from the lamp which passes through the globe unchanged in direction. The appearance is, therefore, that of a lamp surrounded by a non-luminous globe. The only evidence of the presence of the globe is produced by stray light and imperfections in the globe which cause it to appear faintly visible. In Fig. 13*b* is shown a globe giving spread transmission. Here the globe itself appears luminous as the light is broken up at the surface so that the light-source is not visible. At the portion of the globe directly between the light-source and the eye, the globe will appear the brightest, as spread transmission produces the maximum intensity of light in the direction of direct transmission. Near this point the globe will also appear bright, as the light-rays slightly spread from the direct path are nearly as great in intensity as the light-rays in the direct path between the light-source and the eye. However, at angles far from the direct line between the light-source and the eye, the high intensities of the transmitted light are not toward the eye and the intensity of the light in the direction of the eye is low, as will be seen from the diagram. The appearance of the globe will, therefore, be that of a luminous globe with a bright spot at the center or close to the direct line between the light-source and the eye, while beyond this spot and near the edges of the globe, the briliancy will be much less and the globe will appear comparatively dim. The light-source itself will not be visible, because all the rays are slightly spread or broken up.

Fig. 13*c* shows the effect which is produced with a globe giving perfect diffusion. The globe appears luminous as no light passes directly through. By the cosine law the maximum intensity of light from the surface is normal to the surface so that an eye will receive this intensity in the direction of vision normal to the surface. By the cosine law again, and as the figure shows, the eye will receive from other parts of the globe, an intensity of light proportional to the cosine of the angle between the line of vision to the globe and the normal to the surface. However, the actual area of the surface which is included in any given angle from the eye increases as this surface is tipped away from the line of vision. This increase is proportional to the cosine of the angle of tipping. This compensates for the decrease in the in-

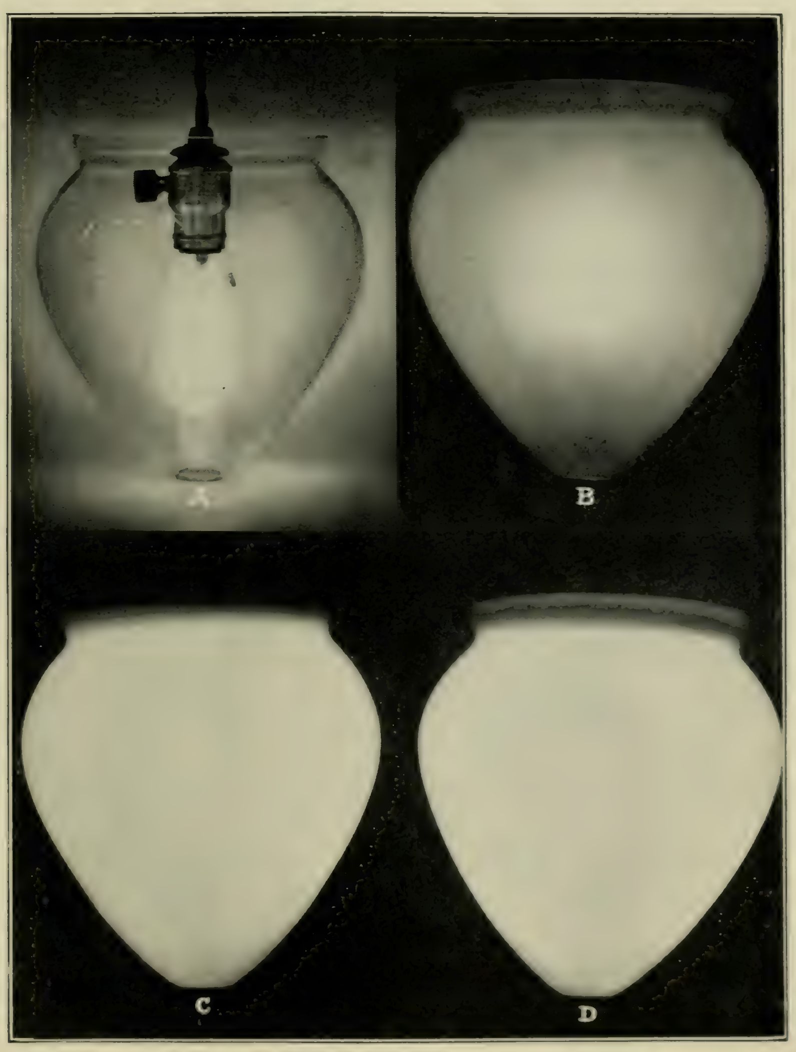


Fig. 14.—Lighted globes giving dffferent kinds of transmission. *a*—Direct transmission. *b*—Spread transmission. *c*—Diffuse transmission. *d*—Combination of direct and diffuse transmission.

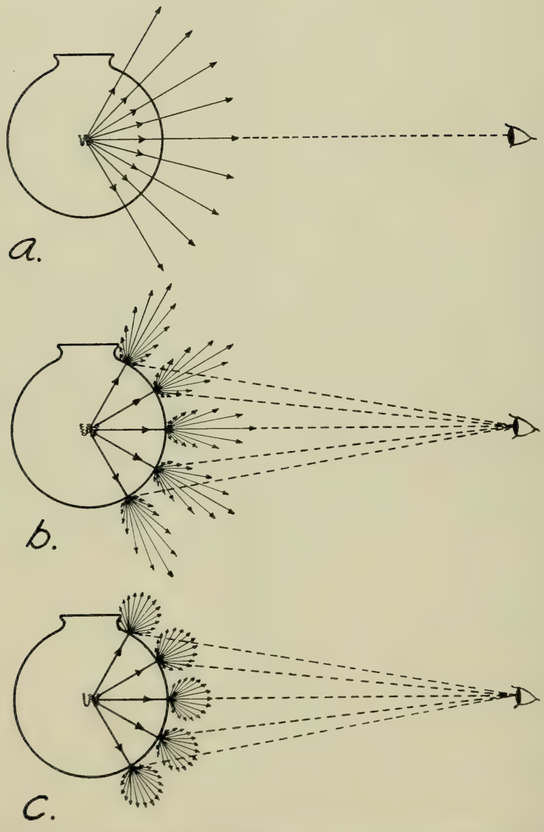


Fig. 13.—Operation of the laws of transmission in the case of globes. *a*—Globe giving direct transmission (clear glass). *b*—Globe giving spread transmission (etched or rough glass). *c*—Globe giving diffuse transmission (opal globe).

tensity of light so that the net result is that every part of the globe appears equally bright. In other words, while the intensity of light in a small solid angle from the globe decreases as the surface is tipped away from the direction of vision, the tipping means that a greater area of globe is sending light to the eyes in the same solid angle, so that the brightness is the same no matter how much the globe is tipped. The globe is therefore equally luminous over its entire surface.

If we have this perfect diffusion of light and at the same time a small amount of directly transmitted light, the globe will appear equally bright over its entire surface, but at the center will appear the exact form of the light-source. This outline of the light-source is caused by the directly transmitted light and of course shows brighter than the globe.

Fig. 14 shows actual photographs of globes giving these effects. Fig. 14*a* shows a globe giving direct transmission, obviously a clear globe made visible only by stray light. Fig. 14*b* shows a roughed glass globe which gives spread transmission. The result is exactly what would be expected, a bright spot at the central part of the glove and outside of this a less brilliant appearance. Fig. 14*c* shows an opal globe which gives diffuse transmission, and as indicated above, the globe appears luminous over its entire surface. Fig. 14*d* shows a lighter opal globe which gives a combination of diffuse transmission and direct transmission. The globe is equally brilliant over its entire surface with the exception of the actual image of the light-source itself showing brighter at the center by directly transmitted light.

With the combination of spread transmission and diffuse transmission, the globe would appear bright over its entire surface as in Fig. 14*d*, but instead of the image of the light-source at the center, there would be a spot of light similar to that in Fig. 14*b*. In other words, the undiffused light, instead of being directly transmitted would be spread slightly from the direct path.

APPLICATION OF THE SECONDARY LAWS OF TRANSMISSION.

The principal materials transmitting light and suitable for lighting equipment, are as follows, classified as to the character of their transmission:

Direct transmission, clear glass.

Spread transmission, etched or roughed glass, ribbed glass, etc.

Diffuse transmission, opal glass (perfectly diffusing).

Direct and diffuse transmission, opal glass (imperfectly diffusing).

Spread and diffuse transmission, opal glass (imperfectly diffusing and roughed inside or outside).

In discussing the usefulness of these materials for various kinds of lighting equipment, it is necessary to ask ourselves first, what is the object of a globe enclosing the lamp? When this object is solely that of mechanical protection of the lamp, then clear crystal glass is the best material to be used. This transmits the light directly and has a minimum absorption. Clear crystal globes are used for this purpose, especially on shipboard, and for outdoor use. It would seem that clear crystal glass globes have little field of usefulness other than that of protecting the lamp, except when forming a part of the lamp itself and aiding in its operation, as in the incandescent lamp and the enclosed arc lamp.

When the object of using the globe is to obtain diffusion of the light, opal glass giving perfect diffusion is the best to use. Obviously roughed crystal glass, Fig. 14*b*, and opal glass giving imperfect diffusion, Fig. 14*d*, are not as desirable as the perfectly diffusing material.

Where both diffusion and redirection of the light in certain directions is desired, a Holophane prismatic globe can be used. As pointed out above, the interior prisms of the globe diffuse the light in horizontal directions. The exterior prisms of the globe redirect the light in vertical directions. One drawback to the widespread use of such globes has been the large area of light-sources in use, rendering effective prismatic action by refraction difficult. With the introduction of the Mazda C lamp, however, which has the filament confined within a small volume, and with the recent mechanical improvement in the globe by which the prisms are enclosed within the glass, this type of globe is being used to a considerable extent especially in outdoor service.

As pointed out above, a spread transmitting medium, such as roughed glass, should not be used where diffusion of light is desired, both on account of the appearance, and on account of the high brilliancy accompanying the lack of perfect diffusion.

While this means that roughed glass should not be used to interpose between the light-source and the eye, it does not mean that roughed glass has not a distinct field of usefulness. Wherever a slight spreading of the light is desired, and the medium does not come between the light-source and the eye in the ordinary directions of vision roughed glass is a better medium than opal glass. Fig. 15 illustrates such a case. A deep reflector is used over the lamp, the reflector coming down to such an angle of cut-off that in ordinary directions of vision the eye never sees the light-source itself, except as diffused by this deep reflector. It is desired, however, to use a diffusing medium over the bottom of the

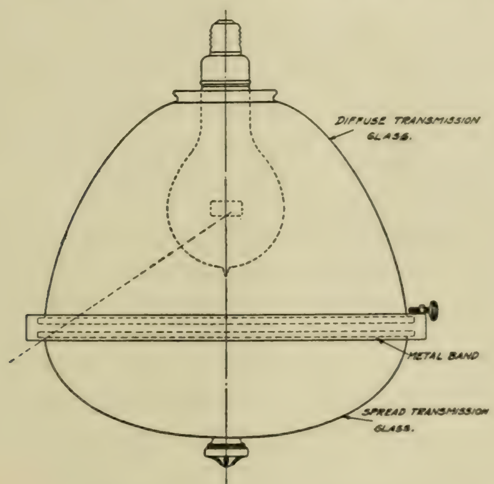


Fig. 15.—Reflector-bowl, in which the bowl may properly be made of a spread transmitting medium.

reflector in order to break up striations in the illuminated surface, decrease the glare due to high lights and present a more attractive appearance. A spread transmitting medium is exactly what should be used for such a case as this. It will ordinarily have a higher transmission of light than a diffusing medium; it will not destroy the directional value of the direct light from the lamp and the light reflected from the interior of the reflector; it will slightly spread these rays from their direct path and will effectively break up all streaks or striations which might otherwise appear in the illuminated surface. Furthermore, the glass

will appear slightly luminous due to the small amount of light which is spread to very wide angles and will thus reach the eye in the ordinary directions of vision. Of course, from directly underneath, the spread transmitting bowl will show a spot of light, but under ordinary conditions of interior illumination, a light-unit is never viewed from directly below. Practically always, when it comes within the range of vision at all, it is viewed at an angle much nearer the horizontal than the vertical and the reflector in this construction should always be deep enough to thoroughly shield the lamps in these ordinary directions of vision. If diffusing glass (opal) were used for this bowl the diffusion would mean that the bowl would appear equally bright in all directions viewed and consequently in the directions of ordinary vision. The brilliancy would therefore, be much greater than that of a bowl of spread transmitting glass; in fact the bowl would be even brighter than an opal ball enclosing the lamp and much of the redirecting value of the unit would be destroyed. On the other hand if this unit were inverted in general construction so that the dividing line came above or near the light-source, the lower piece would be depended on to shield the eye. A spread transmitting medium (such as etched glass) would then be out of place on account of the spot appearance and the brilliancy. A diffusing medium (such as opal) would be the correct material. Of course, much of the redirection and engineering value of the unit would be lost in the invented construction, but with this construction given, the design should still follow the principles of good engineering as far as possible.

It will be seen that glass giving spread transmission, of which roughed or etched glass is typical, is the material to use when a slight spreading of the light is desired, with a luminous effect to the material when viewed at wide angles. It is not advisable to interpose glass of this character directly between the light-source and the eye. It is true that this glass, in the form of etched shades and globes, is widely used interposed directly between the light-source and the eye, but this practice is due to the low cost of this material and cannot be commended from the engineering standpoint.

Materials giving the combination of direct transmission and diffuse transmission, of which imperfectly diffusing opal glass is

typical, are probably out of place in any lighting equipment. While such material could be tolerated in places where the medium does not come directly between the light-source and the eye, nevertheless, a spread transmitting medium such as roughed or etched glass is more desirable for such requirements.

Materials giving a combination of diffuse and spread transmission, such as etched opal glass, which is imperfectly diffusing, cannot be condemned except in certain cases. Some types of this glass give an appearance as desirable as perfect diffusion and the slight variation from the appearance of a perfectly diffusing glass cannot be counted strongly against them.

CONCLUSION.

It is beyond the province of this paper to go into greater detail as to the correct use of various materials in illumination design work. Such problems form part of the usual work of the illuminating engineer and especially of the designer of illuminating appliances. The aim here has been to place in concise form the fundamental principles involved. These fundamental principles do not change with the changing problems that confront us. Each class of material has its field of usefulness and each engineering requirement has its material which will best meet the requirement.

ABSTRACT OF A PAPER ENTITLED, OBSERVATIONS ON LIGHTING FROM A GLASSMAKER'S STANDPOINT.*

BY A. DOUGLAS NASH.

The development of glassware for lighting purposes has been compulsory. The ever increasing brilliancy of the light source has made it necessary to produce some kind of a medium to protect the eyes. In the earlier days this was not necessary, for the reason that the light was not so brilliant. Hence, crystal glass roughed or polished, with suitable and attractive designs etched or cut on the surface was used almost exclusively. For certain purposes, this type of glassware will never be improved upon, but it is manifestly ridiculous for lighting engineers to permit the use of this where reflection is one of the important features. Many times the quality of glass is sacrificed to enable the contractor to meet prices, and the glass element is reduced to such an extent that nothing but so-called "C. R. I." could possibly be used. In most fixture contracts, the glass element runs in the neighborhood of 20 per cent. of the total value of the contract, and yet it is the most important. The metal element *does not* and *can not* increase the efficiency of the lighting scheme.

We naturally come to the question: What is perfect light? We may differ in our opinion regarding this, but my theory of perfect light is manifest on a spring day when the sun is shining but is hidden by beautiful snowy clouds. Another example is the light which is present in a shady grove. Some cloudy days are perfect in this respect, but it is essential that the atmosphere be clear and without glare. Perfect light then is light which produces little or no intense contrast; a light which does not cause very sharp shadows. In other words, as nearly a natural blue skylight as possible without glare. It is not always necessary to have perfect light insofar as the color of the light itself is concerned. Light may be tinged with any color so long as the actual light is sufficient for the purpose intended, and that pur-

* This paper was given before the New York Section of the Illuminating Engineering Society, May 11, 1916.

pose is not the determination of color values. One can be reasonably sure that the index of absorption will prevent the use of sufficient color for it to have any appreciable effect upon the eyesight.

The most perfect artificial lighting system is that in which the major portion of the illumination is received from extended surfaces of low brilliancy, and may be called the *indirect* method. We have now so-called *total* and *semi-indirect,* but both of these have radical imperfections. The *total indirect,* while giving a soft light, produces a contrast between the opacity of the bowl and the brilliancy of the ceiling. The bowl or fixture silhouettes itself against the ceiling. This is an imperfection. The normal *semi-indirect* produces a reverse condition. The brightness of the bowl is too manifest. It creates ugly fixture shadows, and in most cases becomes too prominent a feature in the general decorating scheme.

It therefore becomes necessary to produce something combining the good qualities of both, and eliminating their bad qualities. This can be done in several ways.

One is by the use of a bowl sufficiently opaque to prevent too much light penetration, and having an inner surface of a highly reflective character. Owing to the fact that *some* light must pass through this bowl, it is manifestly impossible to mirror it to produce its reflective quality. *It must be intensely white.* This type of bowl must depend upon its *opacity* to reduce contrast brightness, and is more particularly suited to commercial work.

Another way is to use a similar type of bowl to the one previously noted, but to reduce contrast brightness by treating the outer or inner surface of this bowl. This may be done by painting or enameling. This method is very effective, but not very permanent unless done with vitreous colors and fired on at a fairly high temperature. In most cases this would be impossible owing to the size of the pieces of glass and the risk of their flying during the process.

Another method is to produce the effect by casing it with a colored glass to correspond with the color scheme of the room in which it is to be placed. This method is better adapted to residential use, or for use where individual color schemes are desired, and the question of price is not so important. This method

precludes the possibility of making very large units, as the finest effects can only be produced by the so-called "off-hand" or "hand-made" method.

(I consider it a great mistake to drill glassware anywhere but in the bottom, as the natural molecular formation of glass is centrifugal, and this idea of drilling three or more holes to support a large bowl is as risky as to partly sever some of the links of a chain. All bowls should either be supported from the center or from a properly designed rim or edge by a properly designed support which will not bind at any point to produce an uneven pressure.)

A more radical method of producing light without contrast brightness is the use of an internal transparent reflector, this reflector to be made of any desired color. This color diffuses itself through the bowl, and yet at the same time, owing to its highly reflective inner surface, produces a wonderful semi-indirect light without contrast brightness. The particular advantage of this method is in the fact that it can be applied to any system already installed. It has not the advantage of the previous system though, when the fixtures are unlighted. In this case the bowls would always remain white or their original color.

Some manufacturers may say that their daylight glass is much more efficient than others. This is more or less true, but a question of "luck." One manufacturer is fortunate enough to have a batch sufficiently oxidizing to successfully use copper as a coloring agent. This gives a blue glass without the violet tinge, and is less absorbent than the glass which another manufacturer may be forced to color with cobalt. The latter is more apt to give the better daylight color by reason of this violet tone, although the best would no doubt be produced with both, but the absorption would be out of all proportion to the result. In fact, any method for correcting the color of light by this method is too substractive for real practical permanent use.

We must not forget the most important element entering into successful lighting by the indirect method. This is the treatment of the ceiling. This must be relatively equal to the lighting unit in its co-efficient of reflection. Many indirect installations are made without regard to the ceiling conditions. Ugly exposed

steam and sprinkler pipes are left to cast their shadows on a ceiling, and thus reduce, to a certain extent, the efficiency of the lighting scheme. All this can be overcome by the proper treatment of ceiling and pipes together, or by using a sealing board.

There is one appeal I would like to make to owners, architects, engineers and fixture manufacturers. Bear in mind that the glass manufacturer cannot be eliminated from this lighting game. He has saved you many a time, and will again. He needs your consideration at this time. There is no industry wherein materials have been affected to such a marked extent. Many of the most necessary materials to many glass manufacturers are absolutely unobtainable, and many others have had to go to extraordinary expense to change their formula. They themselves have advanced prices to only a slight extent, compared with the conditions they are required to face. To-day there are reasons why one type of glass is more expensive than another, and it behooves architects to make themselves familiar with these conditions before drawing up specifications which might, with absolutely no intent, give all the advantage to one manufacturer because he was able to make his particular glass with *soda,* while another would have to use *potash,* a difference of about 2,500 per cent. in the cost.

Glass having all the characteristics of present diffusive or alabaster glasses, was made between 40 and 50 years ago. The formula contained practically the same ingredients as the present day formula. True, from a technical standpoint, the chemicals then did not have the same name. This, however, is begging the question, for alumina, for instance, would be the same material, were it contained in feldspar or fireclay. This is virtually what has occurred in this type of glassware. It was necessary to incorporate certain ingredients, and these were secured from certain mineral or chemical sources which were available at that time. Science having advanced somewhat in 40 years, materials are more refined, and instead of using a material containing certain requisite chemicals, we get those chemicals to-day refined, and under their proper nomenclature. An instance of this condition which will appeal strongly to even those who are not familiar with chemistry, is the distinct change which has occurred in the character of the glass produced from uranium.

This chemical produces a golden yellow when used as a coloring agent in glass. Twenty years ago a yellow produced with uranium would have had a peculiar fluorescence. This characteristic is not present in a glass made with uranium to-day. This is explained probably by the recent discovery of radium. Radium and uranium are present in two ores; one is pitchblende, the largest deposits of which are in Joachimsthal, and is the ore from which radium was first taken. The other is carnotite, the largest deposits of which are to be found in Colorado. In each case these ores have both uranium and radium present. When uranium was first refined, radium was not known, and it is an undoubted fact that uranium oxide, produced prior to the discovery of radium, contained an appreciable amount of this element. The fluorescence previously referred to was undoubtedly due at that time to radio-activity.

When we speak of diffusive glasses we intend to convey the fact that they are different to opal glass or prismatic glass, although each of these glasses will diffuse light in the true sense of the word. Architects are prone, in writing glass specifications, to include the trade names to certain glasses, which are as different, in their peculiar characteristics, as a crystal glass would be from a green. In three or four names of glasses given as meeting the requirements of a specific case, one or two of these glasses would cost something like half what the rest would to produce. This is due to the fact that one is a diffusive glass of the alabaster type, and another is of the opal type. The specifications for glass should be of two or more classes. In other words, glasses of the alabaster type should be separated from glasses of the opal type, just as much as glasses of either of these types should be separated from prismatic glass. This is a condition which can only be overcome by the glass manufacturers submitting the characteristics of their various types of glassware to a committee, whose duty it shall be to separate them into their various classes. There is an institution which has recently been formed, that seems to me could be of great help in this matter. I refer to the Building Data League. Little is known about glass by the uninitiated, and it is necessary that all information outside trade secrets should be made available to the architect. I would not advocate the glass manufacturer making any specific claim

for his product, but would suggest that he leave that to the committee. He would no doubt be invited to submit his ideas, and possibly to act upon the committee. I submit this to the consideration of the glass manufacturers.

So far as colored glasses are concerned, I do not suppose it is necessary to consider these from a truly commercial standpoint, for the reason that they have not entered very largely into the lighting field, except in a few minor cases where green cased glass has been produced. Most colors for lighting glass have either been produced by paint, or by the use of small pieces of flat rolled colored glass, leaded together. However, one may safely say that there is hardly any medium by which colors can be given so true a value as through the medium of glass. Of course, in the product I am most interested in, color has played a very important part. It is generally assumed that our glass must be, and always is, iridescent. This is not so. Many of our most notable productions have been based entirely upon the reaction of one chemical upon another, to produce the desired result. Furthermore, we have never used paint of any kind to produce a result, but have always created our colors in glass itself, and applied them in their molten condition on the end of the usual glassmakers' iron, and not by the use of a brush. This has lead in some cases to criticism. The public have assumed that certain of our products were painted, and badly painted at that, and had not realized that these colors and designs are applied in so primitive and crude a manner. While we would not necessarily consider that in using paint we would be "painting the lily," we have felt that to keep at the top of the ladder as producers of *art-glass,* it was necessary to do everything we did do in *glass,* and not on some other material.

ABSTRACT ON PAPER ENTITLED, BUOY AND CAR LIGHTING.*

BY GEO. E. HULSE.

This paper describes the application of Pintsch gas (oil gas) and acetylene to the lighting of railway cars and as aids to navigation. It is divided into four parts, as follows:

1. Car Lighting by Pintsch Gas.
2. Lighting Aids to Navigation by Pintsch Gas.
3. Car Lighting by Acetylene.
4. Lighting Aids to Navigation by Acetylene.

CAR LIGHTING BY PINTSCH GAS.

Adaptability.—Pintsch or oil gas is used for car lighting because of its richness, and the fact that it is not affected by compression to pressures which give sufficient storage capacity.

Manufacture.—It is manufactured by the destructive distillation of gas oil in iron or clay retorts externally heated, or internally heated generators, and can be generated at low pressure and compressed to its storage pressure or manufactured in generators at the working pressure desired.

Distribution.—It is distributed from storage holders through pipe lines to the railroad yards, at 10 atmospheres pressure or can be compressed into steel bottles at 100 or 150 atmospheres pressure for use at isolated points.

Car Equipment.—The car equipment consists of a welded steel gas holder, filling valves, pressure gauge, and pressure regulator, together with the necessary high and low pressure piping.

Burners.—The earlier type of lamps employed a union jet burner, generally in clusters of four; the lamp being of the regenerative type.

At present incandescent mantles are used exclusively. The mantles are of two sizes, 27 and 90 candlepower. The gas pressure used is 2 pounds per square inch. The burner is non-

* Abstract of a paper presented before the International Gas Congress, September 27, October 2, 1915.

The Illuminating Engineering Society is not responsible for the statements or opinions advanced by contributors.

This paper is printed in full in the proceedings of the International Gas Congress, 1915, p. 346.

adjustable in regard to air and gas supply as the quality of gas is uniform, and the pressure constant. The mantle is attached rigidly to the lamp by a screw threaded refractory holder.

The small mantles give 27 candlepower with a gas consumption of 0.85 cu. ft. per hour; the large mantle 90 candlepower with a consumption of 2 cu. ft. per hour.

Regulator.—A special form of pressure regulator is used to reduce the holder pressure to the burner pressure.

Extent of Application.—Pintsch gas has been applied to about 246,000 cars, of which 40,259 are in the United States and Canada. There are ninety-five gas plants in the United States and Canada from which gas is sold to the railroads at a uniform rate.

LIGHTING AIDS TO NAVIGATION BY PINTSCH GAS.

Owing to its capacity for storage Pintsch gas is especially adapted to lighting aids to navigation, particularly floating buoys or beacons where constant attendance is not feasible.

Buoys.—The buoy is a welded steel shell of suitable shape, with the lantern mounted on a suitable super-structure. The shell acts as a container for the gas under pressure, which is supplied to the lantern through a pressure regulator.

Lantern.—The lantern is made so that it cannot be extinguished by gales or high seas. In order to render the light visible at the maximum distance a lens of the Fresnel belt type is employed. The diameters of these lenses vary from 200 to 500 millimeters. In order to give the light a characteristic and economize gas consumption an automatic flashing mechanism is employed which operates by the flow of gas to the burner.

Burners.—Both mantle and flat flame burners are employed as the source of light.

Period of Operation.—Buoys will operate on one charge of gas from 55 to 528 days, depending upon the size of the buoy body, the consumption of the burner, and the light characteristic.

Charging With Gas.—Buoys are charged with gas either from large storage holders and compressors installed on lighthouse tenders or from high pressure flasks.

Beacons.—For the operation of stationary beacons or light ships the gas is stored in high pressure flasks and led directly to the burners through proper regulators. The same type of lan-

terns are used as for buoys; for large beacons the bull's-eye type of lens is employed. This lens is revolved by a motor driven by the flow of gas to the burner. Automatic clocks driven by the same means provide for extinguishing the light during daylight hours.

CAR LIGHTING BY ACETYLENE.

Production.—Acetylene (C_2H_2) is produced by the reaction of calcium carbide and water. It is manufactured by bringing calcium carbide in contact with water in so-called generators which are either automatic or non-automatic. After generation it is passed through purifiers to remove the impurities contained in commercial carbide.

Acetylene cannot be stored and transported in plain cylinders under pressure on account of its liability to dissociate from high temperature or concussion. It can be stored in cylinders filled with porous material which prevents the propagation of the explosion. To increase the storage capacity of these cylinders the acetylene is dissolved in acetone. At 10 atmospheres gauge pressure a storage holder of this description will contain 100 times its own volume of free gas.

Car Equipment.—The car equipment is practically the same as used with the Pintsch system.

Burners.—Acetylene is used in special types of luminous flame burners, at a pressure of 2.7 in. water column. It gives a candlepower of from 20 to 45 per cubic foot according to the size of the burner.

The problem of using mantles with acetylene has not been solved satisfactorily with the injector type of Bunsen burner.

The Dalen system employing a mechanical mixer for air and acetylene, operated by the flow of gas to the burner, and supplying this mixture to the burner nozzle, has given very satisfactory results. Mantle burners of this type give as high as 150 candlepower per foot of gas used.

LIGHTING AIDS TO NAVIGATION BY ACETYLENE.

Practically the same apparatus for utilization of the gas, lanterns, flashing mechanisms, and lens arrangements are used for acetylene as for Pintsch gas.

Storage.—The storage arrangement is different. In the type most used the body of the buoy is filled with pockets into which are placed cylinders charged with acetylene dissolved in acetone, under 10 atmospheres pressure. These cylinders are connected directly to the lantern through the pressure regulator. The same arrangement is used for stationary beacons.

Buoys are also used in which the acetylene is generated from the action of sea water on carbide in the buoy itself, automatic devices being employed to control the amount of gas generated.

ABSTRACT OF PAPER ENTITLED, UNSTABLE STATES IN ARC AND GLOW.*

BY W. G. CADY.

Many of the peculiarities in gas discharges can best be understood by reference to their characteristic curves, a typical example of which is shown in Fig. 1. This shows qualitatively the voltage-current relations in the case of a discharge gap of constant length. OA is the feeble "saturation current," and AB the glow discharge, in which with increasing current the cathode becomes incandescent. Along BC the glow changes suddenly to an arc. CD is the arc discharge on the "first stage," in which, owing to the relatively low temperature of the anode, there is still a glow at the positive end of the discharge. DF represents the sudden change from glow to arc at the anode, so that FG is the final form, or "second stage" of the arc. In any practical case, the change from one type of discharge to the next is discontinuous, depending upon the supply e. m. f., as indicated by the slanting lines in the diagram. If a line is drawn through a point on the E axis corresponding to the supply e. m. f., the tangent of its angle of slope is equal to the external resistance of the circuit. The condition of stability at any point is, that the straight line slope more steeply than the curve. Thus if E_1 is the voltage of the supply, a discharge can be stable at M or N, but not at P. At B the discharge becomes unstable, changing abruptly to a first-stage arc at Q. C, D, and F are similar unstable points for increasing or decreasing current. If the supply e. m. f. is low, as at E_2, only a second-stage arc is possible.

The writer has observed the transition from first to second stage of the arc in the case of a large number of metals and carbon.[1]

An instability in the discharge is sometimes occasioned by traces of impurities on the surfaces of the electrodes. This effect is well known in the case of the cathode. At the anode in a glow

* Abstract of a paper read before the New York Section of the Illuminating Engineering Society in joint session with the New York Section of the American Electrochemical Society, New York, Nov. 11, 1915.

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[1] Amer. Journ. of Sci. 24, p. 383, 1907, Phys, Zeitschr. 14, p. 296, 1913.

or first-stage arc, traces of impurities may serve as nuclei around which the discharge tends to become concentrated, though it is still a glow.

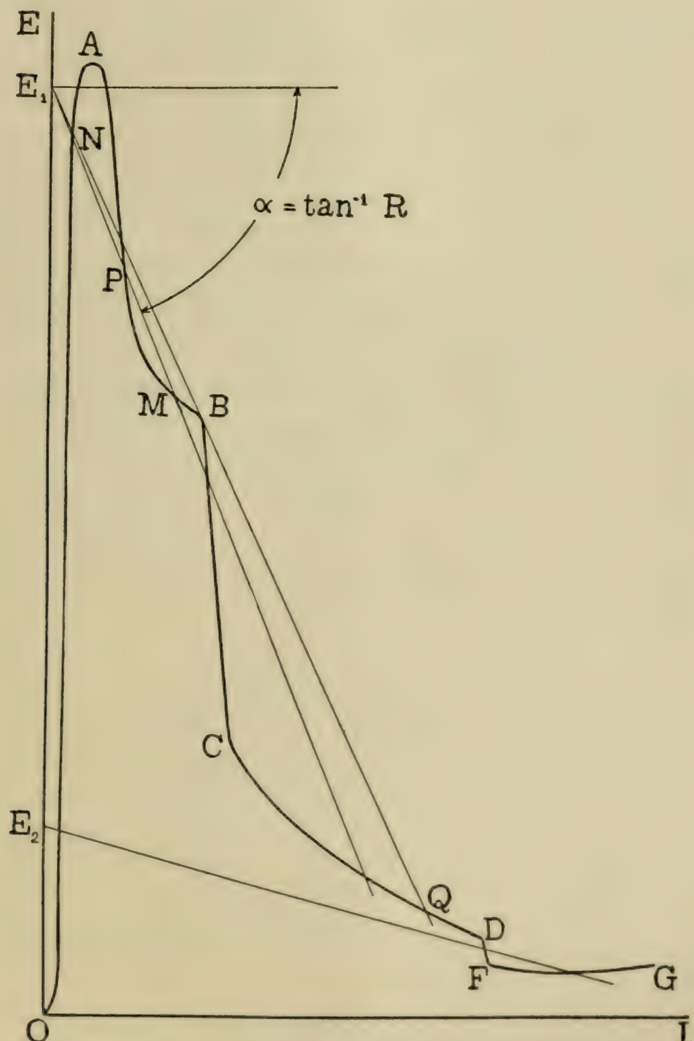

Fig. 1.

A very unusual type of discharge is that in which, as the current increases, an arc appears at the anode, while there is still a

glow at the cathode. The writer has encountered this form of discharge with anodes of C, Ag, Cu, and Hg.

Glow Discharge from a Vaporizing Cathode.—In pure nitrogen, a cathode of pure silver may become heated by the glow discharge nearly, if not quite, to the boiling point, without the formation of an arc. At currents as high as 1.3 amperes the molten metal is white hot and vaporizes very intensely, but the vapor takes little or no part in the conduction of the current, and the characteristic "cathode mantle" proves that the discharge is still a glow. The intense brightness of the discharge indicates that it is of the same nature as the so-called "arcs" that have recently been described by other observers as taking place from cathodes of incandescent tungsten. It is possible that in the case of metals that volatilize with difficulty, the presence of impurities is necessary for the change to a true arc.

Rotations in the Iron Arc.—A curious instability sometimes exists at the anode of an iron arc in air.[2] The iron oxide being more reduced at the base of the discharge than on the surrounding surface of the anode, the discharge continually wanders to regions richer in oxygen, giving rise to a rapid rotation of the arc. Four characteristic types of rotation are observed as the current is increased, indicating progressive changes in the composition of the oxide.

Glow-arc Oscillations.—If two metallic electrodes are very close together, the e. m. f. being sufficiently high and the current small, the discharge can be made to pulsate rapidly between arc and glow. The frequency of oscillation depends on the capacity of the adjacent portions of the circuit, but no capacity in parallel with the discharge is used. As much as 66 per cent. of the direct current energy can be converted into high-frequency alternating current by this means, the frequency being as high as 250,000. The explanation of these oscillations lies in the fact that on the arc phase the energy is too small to maintain the high temperature of the cathode.[3]

In the *"singing arc"* or *"oscillating arc"* of the usual type, a capacity and self-inductance are connected in parallel with the discharge. If the oscillations are strong, the arc goes out and has

[2] Cady, Phys. Rev. 2, p. 249, 1913.

[3] Cady, Amer. Journ. of Sci. 28, pp. 89 and 239, 1909.

to be re-lighted in each cycle of condenser current, thus passing in each cycle through a succession of stages like those shown in Fig. 1.

The presence of a strong second harmonic in the singing arc was demonstrated by the writer as follows: coupled to the condenser circuit in parallel with a carbon arc was a second oscillating circuit in resonance with the first. When the coupling between the two inductance coils was gradually increased, the pitch fell several tones, but at a certain critical point it suddenly sprang up a whole octave. The probable explanation of this is, that when any two oscillating circuits are closely coupled, there are two possible frequencies, one higher and one lower, at either of which oscillations may take place. At a certain state of coupling (about 60 per cent.), when the higher of these two possible frequencies is just an octave above the lower, then if the arc is oscillating on the lower frequency and has a strong second harmonic, the harmonic may be so strongly reinforced as to assume the rôle of the fundamental frequency. The pitch then rises to the higher octave.

TRANSACTIONS

OF THE

Illuminating Engineering Society

NO. 9, 1916

PART II

Miscellaneous Notes

INDEX TO PART II.

COUNCIL NOTES.

Extracts from the official Minutes of the meeting of November 9, 1916.

Place: At the general offices of the Society, 29 W. 39th St., New York, N. Y.

Present: Wm. J. Serrill, president; G. H. Stickney, general secretary; L. B. Marks, Preston S. Millar, A. S. McAllister, C. L. Law, H. Calvert, Wm. A. Durgin, Geo. S. Crampton, M. Luckiesh and D. McFarlan Moore.

The meeting was called to order at 2.00 p. m. by President Wm. J. Serrill.

The minutes of the Council meeting of October 11, 1916, were corrected and approved. The correction involved the lettering of clauses and the insertion of clause (*h*), Sec. 4, Art. III. These changes in the By-laws will be submitted to the members of the Council for vote by letter ballot. The articles, as corrected, are as follows:

CHANGES IN BY-LAWS.

ARTICLE I and II: No change.

ARTICLE III, Section 2: Substitute for clause (*a*), the following: "An application for membership in the Society shall be made upon a printed form prescribed by the Council.

Section 4: In clause (*d*), substitute for the last sentence "This By-law shall be printed on the form used in notifying a candidate of his election."

In clause (*e*), omit "or the Secretary of a Section" from the first sentence. Substitute "Section Board of Examiners" for "Board of Examiners" in the third sentence. Omit the fourth sentence.

In clause (*f*), substitute for the word "admission," the words "admission or transfer." Re-letter this clause (*i*), and insert new clauses (*f*), (*g*) and (*h*) as follows:

Clause (*f*): Applications for membership received from persons not residing within the territory of any section shall be referred to the General Board of Examiners.

Clause (*g*): The General Board of Examiners shall collect such information concerning the eligibility of all applicants as may be necessary to make recommendations to the Council for final action. Each person endorsing an application for transfer or admission to the grade of Member and each person referred to by the applicant shall be requested by the General Secretary to fill out a prescribed confidential form for consideration by the General Board of Examiners. After serving as the basis of recommendations from the General Board of Examiners to the Council for final action, the application and confidential forms shall be kept in the files of the Council.

Clause (*h*): No application for transfer or admission to the grade of Member shall be acted upon by the General Board of Examiners until replies have been received from the number of persons prescribed by the Constitution. In the event of failure to receive replies, or of receipt of unfavorable replies, the General Secretary may call upon the applicant to furnish additional names.

ARTICLE IV: Clause (*a*), change to "The entrance fee for Members or Associate Members shall be $2.50, payable on admission to the Society."

Clause (*b*), add "Honorary members are exempt from the payment of dues."

ARTICLE V: No change.

ARTICLE VI: Clause (*d*), add "Upon the acceptance of the report of the Committee of Tellers by the Council, the General Secretary shall mail a notification of election to each successful candidate. Such notification shall contain a statement of the duration and duties of office and shall be accompanied by a copy of the Constitution and By-Laws."

ARTICLE VII, Section 8: Clause (*e*), substitute the following: "At the first meeting of the Council after he assumes office, the President shall appoint, subject to the approval of the Council, a General Board of Examiners, consisting of three Members to investigate the qualifications of all applicants for admission to membership in the Society and to make recommendations to the Council for final action."

Section 9: Clause (*f*), add "The duties of all committees not specifically defined in the Constitution and By-Laws shall be outlined by the Council at the time of appointment or reappointment."

ARTICLE VIII: No change.

ARTICLE IX, Section 3: Clause (*d*), add "A vacancy in the office of Chairman, Secretary or Manager shall be filled by the Section Board of Managers."

Section 8: Clause (*f*) (new), "As early as possible in the fiscal year the secretary of each section shall submit to the Committee on Finance a budget of section expenses for the fiscal year."

Re-letter clauses *f, g, h, i,* and *j,* to *g, h, i, j,* and *k.*

ARTICLES X, XI, XII: No change.

Upon recommendation of the *Committee on Finance,* payment of vouchers No. 2650 to 2678 inclusive, aggregating $1,375.73 was authorized.

Mr. H. Calvert, Chairman of the *Committee on Finance,* reported on proposed changes in the By-laws (not printed in minutes) limiting material to be accepted by Committee on Papers (see Minute 8 of October 11, 1916). The *Committee on Finance* recommended that definite action be deferred. The report was accepted as read.

A list of resignations was read. Action was deferred until the next Council meeting, pending which the resignations are to be referred to the *Section Membership Committees* and the *Committee on Sustaining Membership.*

Vice-presidents' reports on Section activities:

New York—Written report, C. L. Law.

Chicago—Written report, M. G. Lloyd.

Philadelphia—Oral report, Geo. S. Crampton.

Pittsburgh—No report.

New England—No report.

Mr. Wm. A. Durgin, Chairman of the *Committee on Membership,* made a verbal report for this committee. Subsequent discussion led to suggestions for future membership campaigns.

The question of having a joint meeting with the American Association for the Advancement of Science in December, 1916, was referred to Mr. C. L. Law, Chairman of the Committee on Reciprocal Relations, with power to act. Dr. Edward B. Rosa and Dr. Clayton H. Sharp were appointed representatives of the Illuminating Engineering Society on the governing board of the American Association for the Advancement of Science.

Special reports were submitted by committees-of-one appointed by the President to investigate and make recommendations on assigned subjects:

Mr. L. B. Marks—Head-lamps.

Recommended the appointment of

1. Committee on Automobile Head-lamps.
2. Committee on Railway Vehicle Head-lamps.

These committees would collect technical and other data, especially with reference to legislation; and co-operate with the Committee on Lighting Legislation. These recommendations are to be submitted to the vote of the Council by letter ballot.

J. Arnold Norcross—Lectures for Architectural Schools.

Recommended the appointment of a Committee on Lectures for Architectural Schools. The object of this committee will be to write a lecture or series of lectures on illuminating engineering to be offered before students in architecture. The appointment of this committee was approved.

D. McFarlan Moore—Publication of Transactions in an outside organ.

Recommended that the present plan of publication be continued. This recommendation was adopted.

M. Luckiesh—Correspondence course.
An oral report was given and the question left in Mr. Luckiesh's hands, to give a full report at the next meeting of the Council.

C. L. Law—Street Lighting.
Recommended that a temporary committee be appointed to look into the question of the advisability of forming a committee on street lighting. This recommendation was approved.

M. G. Lloyd—Misleading Statements in technical press.
Recommended the appointment of a committee to correct misleading statements in the technical press. The President was authorized to appoint such a tentative committee, who, in order to permit the Council to judge the scheme, would in a number of specific instances, write letters of correction and submit to the Council for consideration before sending.

Mr. Preston S. Millar, *Chairman of the Administrative Committee on Lectures,* gave an oral report on the publication of the Illuminating Engineering Society - University of Pennsylvania Course of Lectures. These printed lectures will later be for sale to the public and for a limited time at a reduced figure to the membership of the Society.

The resignation of Dr. E. M. Alger, as a director, was withdrawn.

The Council approved the appointment of the following *committee chairman:*

Geo. A. Hoadley, Committee on Education.

The President reported the following additional appointments to committees (see Minute 15, October 11, 1916):

Committee on Finance
J. Arnold Norcross
Adolph Hertz

Committee on Papers
C. E. Clewell
A. S. McAllister
E. J. Edwards
E. B. Myers
C. O. Bond
Alexander Maxwell
O. R. Hogue
R. G. Hudson
W. P. Hurley

Committee on Editing and Publication
O. H. Fogg
Clayton H. Sharp

Council Executive Committee
L. B. Marks
Preston S. Millar
H. Calvert
G. H. Stickney

Committee on Lighting Legislation
O. H. Basquin
C. O. Bond
C. E. Clewell
J. B. Klumpp
A. P. Lathrop
C. L. Law
M. Luckiesh
F. J. Miller
E. B. Myers
G. H. Stickney
L. A. Tanzer
W. H. Tolman
F. A. Vaughn
Thomas Scofield

Committee on Progress
W. B. Lancaster
T. J. Litle, Jr.
F. N. Morton
T. W. Rolph

Committee on Nomenclature and Standards

C. H. Sharp, Secretary
Louis Bell
C. O. Bond
S. E. Doane
W. A. Dorey
E. P. Hyde
C. O. Mailloux
A. S. Miller
A. S. McAllister
P. G. Nutting
E. B. Rosa
W. E. Saunders
C. P. Steinmetz

Committee on Reciprocal Relations with Other Societies

F. Park Lewis
Frank E. Wallis
Louis Bell
G. S. Crampton
Lewis J. Kiefer
D. McFarlan Moore
C. H. Sharp
G. H. Stickney
Walter Neumuller
F. W. Frueauff
L. R. Dutton

Committee on Section Development

L. O. Grondahl
Norman D. Macdonald
T. Elmer Moon
J. J. Kirk
R. G. Hudson

Board of Examiners

Bassett Jones, Jr.
W. Cullen Morris

Committee on Popular Lectures

Sub-Committee on Residence Lighting

J. D. Lee
H. T. Spaulding

Sub-Committee on Elementary Lectures

G. A. Hoadley
M. Luckiesh

Sub-Committee on Office Lighting

E. J. Dailey
G. A. Hoadley

Sub-Committee on Industrial Lighting

C. A. B. Halvorson, Jr.
H. H. Magdsick
R. ff. Pierce

Committee on Sustaining Membership

S. H. Blake
C. O. Bond
S. G. Hibben
H. Thurston Owens
W. H. Rolinson
S. L. E. Rose
E. B. Rowe
C. E. Stephens
W. M. Skiff
W. J. Clark
C. M. Cohn

Committee on Research

P. W. Cobb
E. C. Crittenden
C. E. Ferree
H. E. Ives
E. F. Kingsbury
G. W. Middlekauff
P. S. Millar
P. G. Nutting
F. K. Richtmyer
C. H. Sharp
W. E. Wickenden

Committee on School Lighting

Nelson M. Black
R. B. Ely
L. O. Grondahl
F. Park Lewis
H. H. Magdsick
F. K. Richtmyer
J. D. Lee

COMMITTEE ON MEMBERSHIP

A. L. Abbott
T. M. Ambler
R. B. Brown
W. R. Collier
J. W. Cowles
W. P. Hurley
Harold Kirschberg
J. C. McLaughlin
A. B. Macbeth
D. McFarlan Moore
F. A. Osborne
J. P. O'Shea
R. W. Myers
S. L. E. Rose
Unit Rasin
W. H. Rolinson
R. E. Simpson
C. N. Stannard
Douglas Wood
H. F. Wallace

The entire personnel of the *Committee on Lectures* and the *Administrative Committee on Lectures* was reappointed and approved by the Council:

COMMITTEE ON LECTURES

E. P. Hyde, Chairman
Louis Bell
W. H. Gartley
L. B. Marks
C. H. Sharp
Wm. D. Weaver

ADMINISTRATIVE COMMITTEE ON LECTURES

Preston S. Millar, Chairman
C. E. Clewell
Joseph D. Israel
A. S. McAllister
Wm. J. Serrill
G. H. Stickney

Sub-Committee on Exhibits
Chas. O. Bond, Chairman

Sub-Committee on Finance
Wm. J. Serrill, Chairman

Sub-Committee on Sales
Clarence L. Law, Chairman

Sub-Committee on Tour
F. H. Gale, Chairman

The General Secretary was requested to investigate the expense involved in printing the revised Constitution and By-laws, a membership list and reprints of the Code of Lighting; and to report at the next Council meeting.

The *Administrative Committee on Lectures* was authorized to draw up a resolution of thanks to the University of Pennsylvania for their co-operation on the Lecture Course.

Dr. A. S. McAllister presented for the Council the following resolutions:

MR. C. ALFRED LITTLEFIELD.

WHEREAS, there has been taken from our midst our faithful co-worker, Mr. C. Alfred Littlefield, a charter member of this Society, a member of its Council and its General Secretary for two terms; and

WHEREAS, all members of the Illuminating Engineering Society, and especially the members of its Council have been greatly indebted to him for his untiring interest and activities for the benefit of the Society since its organization; and whereas the Council desires to place these facts on record; therefore be it

Resolved, That in the death of Mr. Littlefield we have lost a personal friend of inestimable worth, a man of irreproachable character, whose sole thought concerning the Society and whose labors in its service were for its upbuilding towards its highest ideals; and be it further

Resolved, That these resolutions be spread upon the minutes of the Council and a copy be sent to the family of our former comrade.

The meeting adjourned at 5.30 p.m.

NEW MEMBERS.

Upon recommendation of the *Board of Examiners,* the following applicants were elected to membership at the Council meeting of November 11, 1916:

SUSTAINING MEMBER.

THE HARWOOD ELECTRIC CO.
Mr. Chas. Hodge, Official Representative, Markle Bank Bldg., Hazleton, Pa.

MEMBER.

ADAMS, FREDERICK D.
Secretary and Treasurer, The United Illuminating Co., 128 Temple St., New Haven, Conn.

TWELVE ASSOCIATE MEMBERS.

AOYAGI, PROFESSOR DR. EIJI
Kyoto Imperial University, Kyoto, Japan.

BEAM, J. W.
Electrical Engineer, Cleveland Electric Illuminating Co., Cleveland, O.

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SUTTON, L. V.
Superintendent, Electric Light and Power Division, Carolina Power & Light Co., Raleigh, N. C.

TILLSON, EDWIN D.
Testing Dept., Commonwealth Edison Co., 28 N. Market St., Chicago, Ill.

TRANSFER TO GRADE OF MEMBER.

COHN, CHARLES M.
Vice-president, Consolidated Gas, Electric Light & Power Co. of Baltimore, 100 W. Lexington St., Baltimore, Md.

ILLUMINATING ENGINEERING LECTURES

AT REDUCED PRICES TO MEMBERS OF THE ILLUMINATING ENGINEERING SOCIETY.

The editorial work on the lectures which were delivered at the University of Pennsylvania during September is in progress and it is expected that the printed volume of lectures will become available early in 1917. All purchasers of tickets for the entire course will receive a volume of the printed lectures without further expense. All members of the Illuminating Engineering Society who file their order prior to date of publication may obtain copies at a price not to exceed $5.00, which price will be

lower than that which after publication date will be made to members and non-members alike. To obtain this reduced price, members should file orders at once with Clarence L. Law, Chairman, Sub-Committee on Sales, Fifteenth St. and Irving Place, New York, N. Y.

SECTION MEETINGS.

Hereafter a member attending any meeting of his section may obtain copies of papers printed in advance of presentation before his own or any other section. The distribution of such advance copies will come at the first meeting following the receipt of the advance copies which will be sent regularly to the Section Secretaries.

In the last number of the TRANSACTIONS (Nov. 20, 1916) a tentative program for the Philadelphia Section meetings was printed. The following tentative programs have since been announced by the Papers Committees of the New York, Pittsburgh and New England Sections:

NEW YORK SECTION.

January 11, 1917.
A Survey of the Automobile Headlight Situation.
Mr. W. F. Little.

February 8, 1917.
Railway Position Signals.
Mr. A. H. Ruud.

March 8, 1917.
(*a*) Maintenance of Residence Lighting.
Mr. H. H. Newman.
(*b*) A paper on gas lighting fixtures.

April 12, 1917.
(*a*) Projectors.
Mr. C. A. B. Halvorson.
(*b*) A paper on industrial appliances.

May 10 or June 14, 1917.
Street lighting meeting.

PITTSBURGH SECTION.

January 26, 1917.
Automobile Headlights and Anti-glare Legislation.
Messrs. E. J. Edwards and P. G. Nutting.

February 20, 1917.
Street Lighting Specifications.
Joint meeting with Pittsburgh Section A. I. E. E.
Mr. H. N. Muller.

March 23 or 30, 1917.
Elementary Lighting Lecture. The Society's standard educational talk to which National Electric Light Association and Jovians, etc., will be invited.
Speaker not determined.

April 20, 23 or 27, 1917.
Subject not decided. Meeting in Cleveland.
Speaker not determined.

May 18 or 25, 1917.
Pennsylvania State Factory Lighting Code.
Mr. C. B. Auel.

June 15, 1917.
Office building lighting and inspection trip through City and County Building.
Mr. S. G. Hibben.

June 23 or 30, 1917.
Excursion and inspection of coal mine lighting. (Trip probably to Greensburg, Pa.)
Mr. Alvin Seiler.

NEW ENGLAND SECTION.

January, 1917.
(*a*) New Arc for Motion Picture Projection.
By Prof. Comstock.

(*b*) New Method of Producing Colored Motion Pictures.
Author to be announced later.

February, 1917.

(*a*) Fundamentals of Illuminating Engineering.
By Prof. Wickenden.

(*b*) Research in Illuminating Engineering.
Author to be announced later.

March, 1917.

(*a*) Lighting Effects within a Modern Photographic Studio.
By John Garo.

April, 1917.

(*a*) Color in Illumination.
By M. Luckiesh.

May, 1917.

(*a*) Street Lighting.
By W. D'A. Ryan.

The program of papers for the coming meetings of the Chicago Section is not yet available in its final form. A tentative list of subjects which are under consideration, but for which the dates have not been chosen, are as follows:

Store Lighting.
Factory Lighting.
Office Lighting.
New Developments in Lighting Equipment.
Street Lighting.
Lighting with Gas.

NEW YORK SECTION.

The New York Section meeting of December 24, 1916, was preceded by a visit to Bedloe's Island, New York Harbor, at 4.00 p. m. in the afternoon. The members and guests were received at the Island by Captain Clifton, Commandant of Fort Wood, who gave an informal talk on the Signal Corps of the Army. Remaining on the Island until 5.30 p. m., the illumination of the Statue of Liberty was inspected. In this way it was possible to see the installation features of the projectors in the daylight and to view the illuminated statue by night, as the excursion boat returned to the Battery. An informal dinner was enjoyed at the Forty-second Street Restaurant after which came the meeting at the Engineering Societies Building. Some 200 members and guests attended the evening program at which Mr. Theodore C. Brown gave an address on "What the Theatre Expects from the Lighting Engineer," and Mr. H. H. Magdsick lectured on "Lighting Liberty."

CHICAGO SECTION.

The December meeting of the Chicago Section was held on the 8th instant at the Edison Building, Vice-president M. G. Lloyd presiding. Mr. M. Luckiesh of the Nela Research Laboratory, Nela Park, Cleveland, gave an address on "Linking Science and Art with Practice in Lighting." About 76 persons were in attendance at the meeting.

NEW ENGLAND SECTION.

The December meeting of the New England Section was held at the Boston City Club, Boston, on December 22, 1916. Mr. C. O. Bond, manager of the illuminating laboratories of the United Gas Improvement Company of Philadelphia, spoke on "Gas Illumination." This was a joint meeting with the New England Section of the National Commercial Gas Association. Mr. Bond's paper was greatly enjoyed by members of both organizations and an interesting discussion followed its presentation.

PITTSBURGH SECTION

A very interesting meeting of the Pittsburgh Section of the Society was held jointly with the Cleveland Section of the American Institute of Electrical Engineers in Cleveland on the evening of November 20, 1916. Mr. H. T. Spaulding presented the popular lecture on "Residence Lighting" demonstrated by room models and sample lighting units. Some 200 members and guests enjoyed this lecture which is one of the products of the I. E. S. Committee on Popular Lectures.

PHILADELPHIA SECTION.

On December 15, 1916, the Philadelphia Section held a meeting at which Prof. W. S. Rodman, of the University of Virginia, presented a paper on "The Lighting Schemes of Thomas Jefferson." Preceding this paper Prof. Geo. A. Hoadley demonstrated and delivered a brief review of the "Elementary Lecture on Illumination." This is a lecture prepared by the I. E. S. Committee on Popular Lectures. Prof. Rodman gave an interesting historical and detailed description of the lighting effects obtained in the home of Thomas Jefferson, Monticello. Due to Mr. Jefferson's appreciation of the importance of adequate daylight and artificial illumination and to the specific specifications which he personally wrote into the builder's plans, Monticello represented possibly America's earliest example of a well lighted residence.

MEMBERSHIP LIST.

The General Office is active in the preparation of a *membership list.* It is proposed to have an alphabetical index of names of the members and an alphabetical grouping of the members affiliated with the various sections. Under each name in the *section list* will appear the official title and business address. A card bearing a "proof" of the entry of each member will be forwarded to him about January 1st. *Each member is urged to be prompt in the return of proof which requires correction.*

NEWS ITEMS.

The Council recently expressed to the Provost and Faculty of the University of Pennsylvania its deep appreciation of the co-operation of the University in the conduct of the Lecture Course held in Philadelphia, September 20 to 28, 1916. The certificate of appreciation was a hand-drawn work of art done on sheepskin and engraved in gold leaf as follows:

The Council of

The Illuminating Engineering Society
expresses its appreciation of the courteous co-operation of the Provost and Faculty of the

University of Pennsylvania

in the joint organization and conduct of the Illuminating Engineering Lecture Course, September 21 to 28, 1916.

Wm. J. Serrill,
President.
G. H. Stickney,
Secretary.

December 14, 1916.

Prof. Geo. A. Hoadley, Chairman of the Committee on Education, reports material progress in the preparation of the Monograph on Illumination.

The Department of Labor of the State of New Jersey has recently

issued a booklet entitled "Code of Lighting for Factories, Mills and Other Work Places." The Illuminating Engineering Society cooperated in its preparation and acknowledgement was given the Society in the following closing paragraph of the Code:

> "The Department of Labor is indebted to the Illuminating Engineering Society for their cooperation and assistance in the preparation of this lighting code and the provisions of this code meet with their approval."

The Department of Labor and Industry of the State of Pennsylvania has a somewhat similar code which was adopted April 13, 1916.

Attention is called to the NEW ARRANGEMENT OF COMMITTEES as printed in the first pages of this number of the TRANSACTIONS. This arrangement gives at a glance a brief outline of the personnel of the committee and its functional activities. The various committees are grouped under the following captions:

1. Standing Committees Authorized by the Constitution and By-laws.
2. Committees for Special Purposes Appointed Each Year and Terminating when Their Purposes are Fulfilled.
3. Committees that are Customarily Continued from Year to Year.
4. Temporary Committees for Special Purposes.

The 1917 Annual Meeting of the SOCIETY OF AUTOMOBILE ENGINEERS is scheduled for January 11, 1917, in the auditorium of the Engineering Societies Building, New York City. At the technical session of the meeting will be presented papers on airplane construction, aerial navigation, types of tractor engines and dynamics of the automobile.

We are glad to announce at this time that PROFESSOR C. E. CLEWELL, Assistant Professor of Electrical Engineering of the University of Pennsylvania, after being ill for several weeks with typhoid fever, has recently been able to resume his work at the University.

PRESIDENT W. J. SERRILL recently attended a joint meeting of the Pittsburgh Section of the Illuminating Engineering Society and the Cleveland Section of the American Institute of Electrical Engineers, held in Cleveland. During the meeting, the Popular Lecture on Residence Lighting was read. These Popular Lectures, prepared by the I. E. S. Committee on Popular Lectures, deal with certain applications of lighting such as the home, public buildings, street lighting, industrial lighting, etc., and are now nearing completion. These lectures will be presented before certain Sections of the Society preliminary to their final presentation to the public. The Cleveland meeting was preceded by a dinner held in the new rooms of the Cleveland Electrical League, whose headquarters are now located at the Hotel Statler.

The NATIONAL COMMERCIAL GAS ASSOCIATION has prepared a 34-page booklet, profusely illustrated, on modern illumination by gas in the home. It is an attractive and useful guide which sets forth all that is latest in gas lighting appliances. A copy may be obtained free by application to the Association at its headquarters, 61 Broadway, New York, N. Y. Additional copies of the

booklet are sold without profit by the association under the plan used by the Illuminating Engineering Society in the distribution of the booklet entitled "Light: Its Use and Misuse."

The NATIONAL ELECTRIC LIGHT ASSOCIATION has, in the course of preparation, a similar booklet on "The Lighting of the Home by Electricity."

MR. S. C. ROGERS, Chairman of the New England Section, attended the meeting of the Council held at the Society's general offices, on December 14, 1916. Mr. Rogers gave an interesting report on the activities of the Section, outlining its future plans. A tentative program of the meetings to be held by the New England Section appears on another page of the TRANSACTIONS.

A meeting of the COMMITTEE ON SUSTAINING MEMBERSHIP was held in Philadelphia at the Engineers' Club, December 15, 1916. Mr. J. D. Israel, chairman of the committee, invited all members of the committee to have dinner with him at the Engineers' Club preceding the meeting.

PROF. GEORGE A. HOADLEY of Swarthmore, Pa., is recovering from an attack of the grippe. He was confined to bed for several weeks.

The General Office solicits suggestions as to how to make Part II of the TRANSACTIONS more interesting and useful to the membership.

OBITUARY.

MR. F. N. MORTON of the Engineering Department of the United Gas Improvement Company, Philadelphia, Pa., died on December 6, 1916. Mr. Morton was an active member of the Society and a member of the present Committee on Progress. Mr. Morton was particularly active in the affairs of the Society during his term of office as Chairman of the Committee on Progress during 1912.

MR. A. C. EINSTEIN, first vice-president and general manager of the Union Electric Light and Power Company, St. Louis, Mo., died unexpectedly on November 19, 1916. Mr. Einstein, shortly after graduation from Washington University, became manager of a mining property in Silver City, Mexico. He returned to St. Louis in 1890 to assume the presidency of the Consolidated Engineering Company. Later, for four years, he held the position of president of the Paducah (Ky.) Electric Light and Street Railway Company. Mr. Einstein was financially interested in the holdings of the Suburban Electric Light and Power Company of St. Louis. He became executive head of the Union Electric Light and Power Company in 1911 and was active in the upbuilding of the company's central station business.